3-D Molecular Designs
...where molecules become real ™

DYNAMIC DNA KIT©

Teacher Guide

The discovery of the structure of DNA by James Watson and Francis Crick in 1953 was one of the most momentous scientific advances of the last century. This discovery has had far-reaching implications for modern molecular science and society. Students using the *Dynamic DNA Kit*© will explore the importance of this discovery through a study of **DNA STRUCTURE**, **FUNCTION** and **BIOINFORMATICS**.

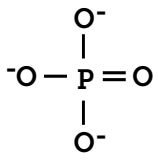
MODELING DNA STRUCTURE

Note: The model is based on X-ray crystallographic structures and is built to scale (approximately 80,000,000 times actual size). For clarity in the model, hydrogen atoms are not shown except for the hydrogens forming the hydrogen bonds between the base pairs (shown in white) and the insertable hydrogen of the hydroxyl group on the 3' carbon of the sugar at the end of each DNA strand. The remaining colors used in the model are standard CPK colors and are as follows:

Carbon atoms: Grey
Nitrogen atoms: Blue
Oxygen atoms: Red
Phosphorus atoms: Orange

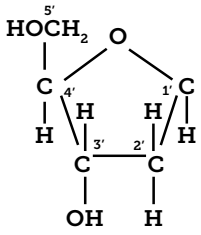
Engage with an exploration of the component parts of DNA nucleotides.
Compare, contrast and identify structures of the constituent parts.

Phosphate (PO_4^{3-})



phosphate

Deoxyribose (5 carbon sugar forming a ring structure)

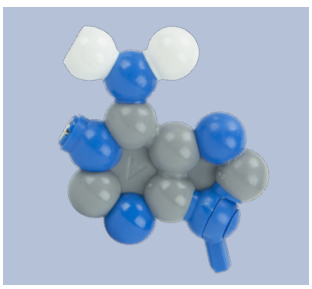


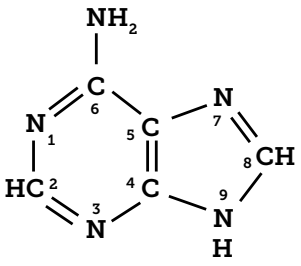
deoxyribose

Note: Parts are shown without capped oxygen.

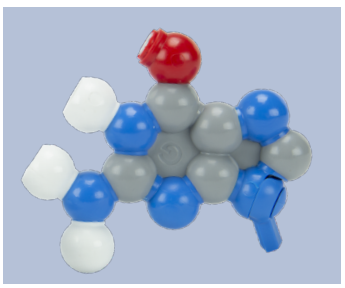
Nitrogenous Bases demonstrate variability with the purines: **adenine** and **guanine**, consisting of two fused rings and the pyrimidines: **cytosine** and **thymine**, consisting of a single ring.

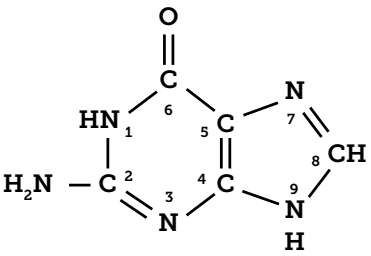
Purines





adenine (A)





guanine (G)

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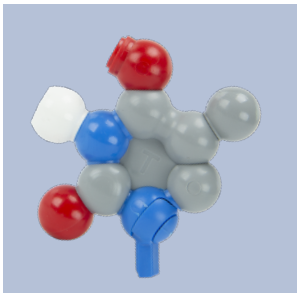
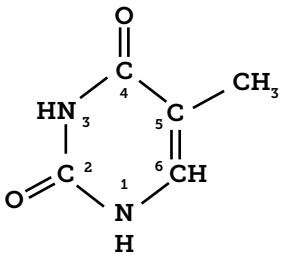
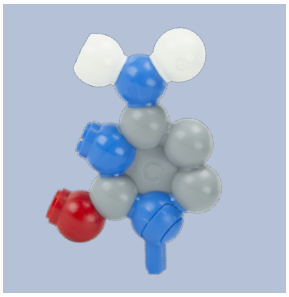
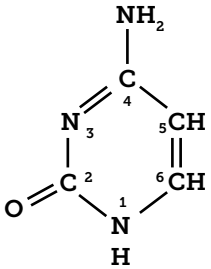
Pyrimidines





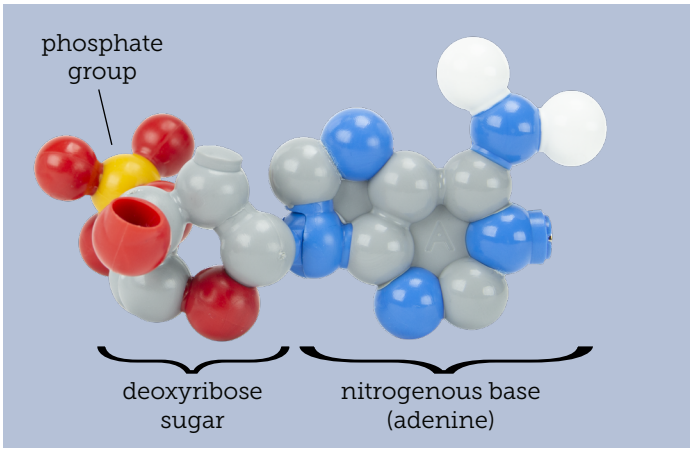
thymine (T)

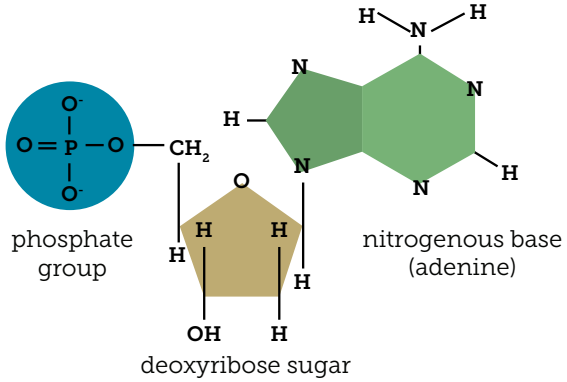




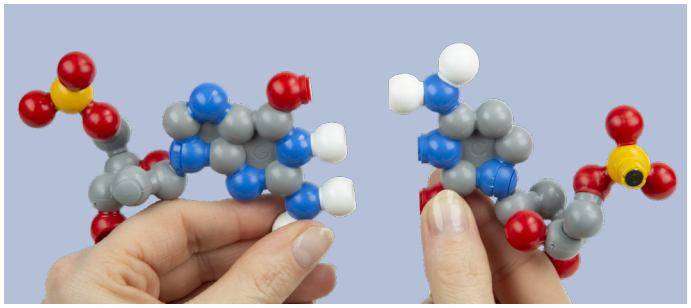
cytosine (C)

Join the constituent parts together using only the posts to form a **nucleotide.** Refer to the assembly instructions if you need directions. There are no magnet connections within a single base.

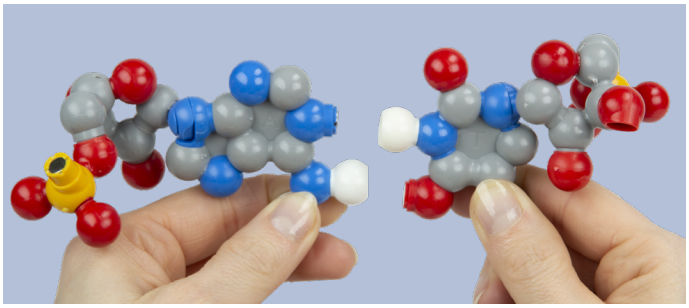




Base pair the complementary nucleotides, G with C and A with T, using the magnets to connect the hydrogen bonds. Ask your students how this base pairing explains **Chargaff's rules**.



Three hydrogen bonds unite the G-C base pair.



Two hydrogen bonds unite the A-T base pair.

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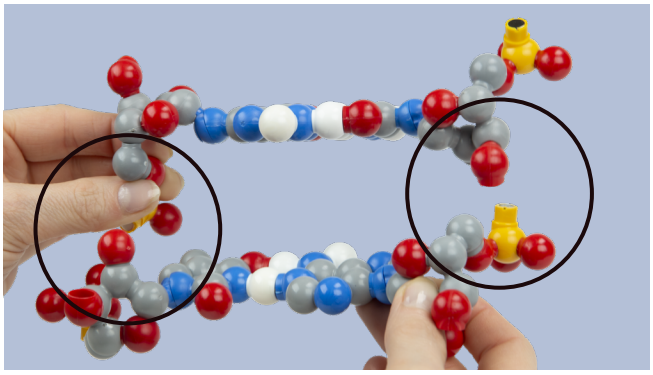
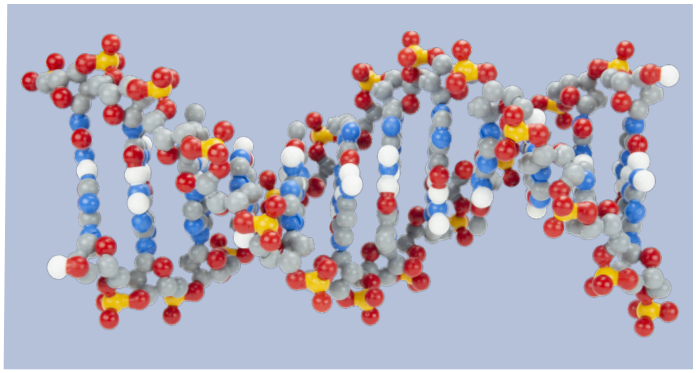
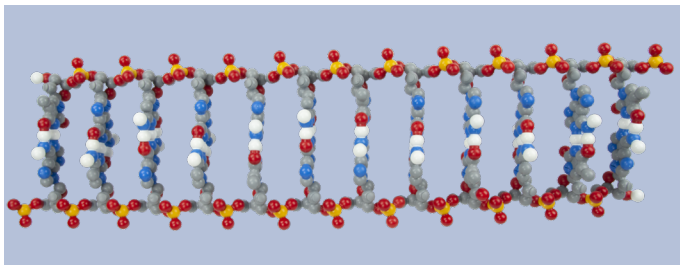


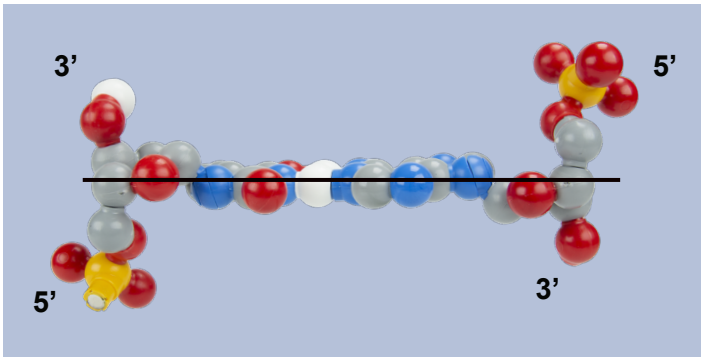


Assemble the base pairs to form a 12 base-pair double helix. You will need to set the DNA on a table and may wish to feed a metal rod through the middle. You'll need a rod to twist and untwist all 12 base pairs at the same time. We recommend you purchase a 24" long, 1/4" thick metal rod from your local home improvement store. Note that *Dynamic DNA* untwists into a flattened 2D ladder and transitions to the classic right handed, 3D double helix, demonstrating the dynamic nature of the molecule.



Non-standard base pairing can occur; however, these base pairs are not compatible with the double stranded helical structure of DNA for two reasons. First, base pairs formed with two purines or two pyrimidines will have a different diameter than the standard G – C and A – T base pairs. Second, when the non-standard hydrogen bonded base pairs form, the polarity of the strands of DNA will be parallel, not the anti-parallel structure consistent with DNA structure.

Have your students identify the component parts of the sides or backbone of the DNA model. Notice that the 5' phosphate of one strand is located opposite the 3' hydroxyl of the complementary strand. The two component strands are anti-parallel, with one strand oriented in the 5'- 3' direction and the other in the 3'- 5' direction. The opposite orientation of the two complementary strands has important implications for DNA replication and transcription.

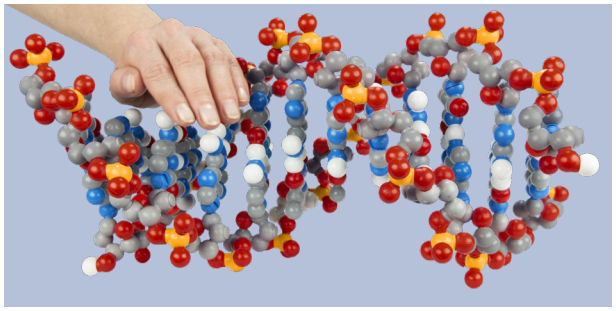


Since the sequence of the nitrogen bases can change without changing the overall structure of the molecule, ask your students to propose how this may contribute to the function of DNA as an information storage molecule.

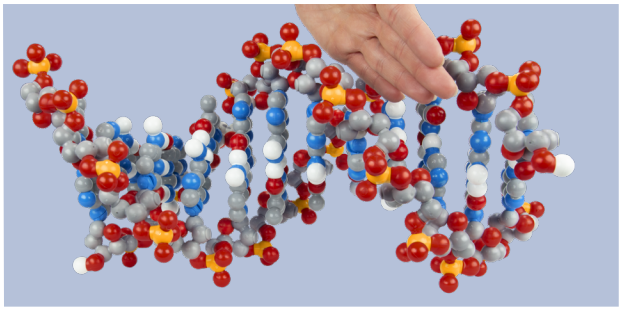
Teacher Guide

An important feature of the DNA double helix is that the two strands are twisted around each other, forming a major and a minor groove.

major groove



minor groove

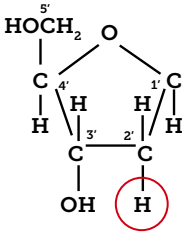


Conversion of DNA Structure to RNA Structure

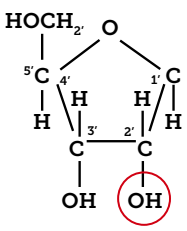
The *Dynamic DNA Kit*© can also be used to compare DNA and RNA structure.

To convert the deoxyribose sugar to ribose, add an oxygen to the 2' carbon of the sugar.

Ask your students, "What is the purpose of the extra oxygen in the RNA?"



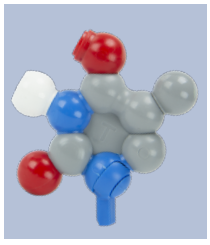
deoxyribose

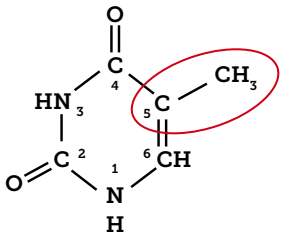


ribose

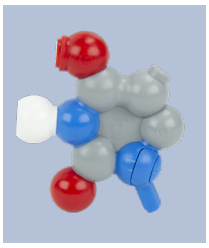
To convert the thymine to uracil remove the methyl group from the carbon in fifth position in the nitrogen ring of thymine.

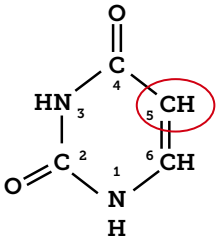
Ask your students, "Why uracil in RNA and thymine in DNA?"





thymine (T)





uracil (U)

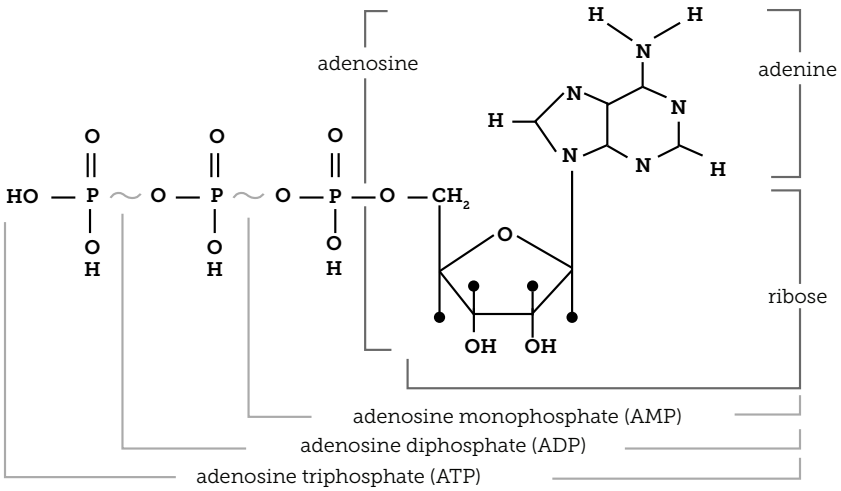
Note: When making the uracil nucleotide, make sure to attach a ribose sugar, not a deoxyribose.

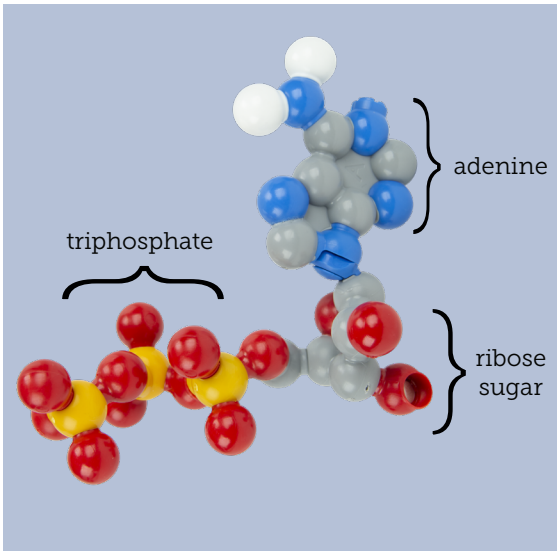
Teacher Guide

Modeling ATP

Adenosine-5'-triphosphate (ATP) is composed of **one adenine nitrogenous base, one ribose sugar** and **three phosphate groups**. ATP is the primary energy currency in biology.

Model AMP, ADP and ATP by adding phosphate groups to the adenine nucleotide phosphate group. Refer to the assembly instructions if you need directions.





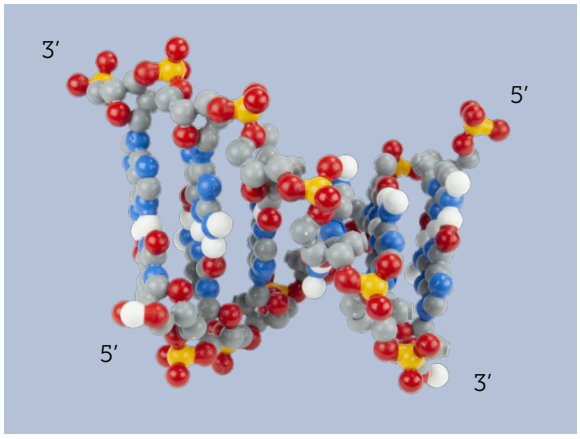
Misconception Alert: The bonds between the phosphate groups of ATP are sometimes referred to as *high-energy* or *energy-rich* bonds. These terms can lead to a misconception that energy is released when the bond is broken. **All chemical bonds require energy to be broken and release energy when they form**.

MODELING DNA FUNCTION

Replication

What is the relevance of DNA replication? Without replication, each cell formed from either mitosis or meiosis would lack the instructions to make the proteins necessary to maintain life. Now that's important!

To teach 3-dimensional aspects of **DNA replication** using one 12 base pair set of *Dynamic DNA©,* assemble a DNA sequence using a combination of 6 base pairs to form a double helix. Use 3 A-T base pairs and 3 G-C base pairs in any order to create your sequence. You will use the other 12 nucleotides to form the new DNA strands. You can create a replication bubble if you have 3 or more Dynamic DNA Kits©.



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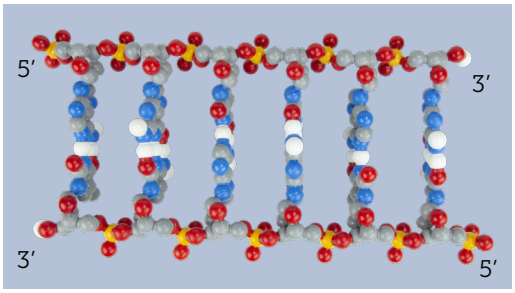
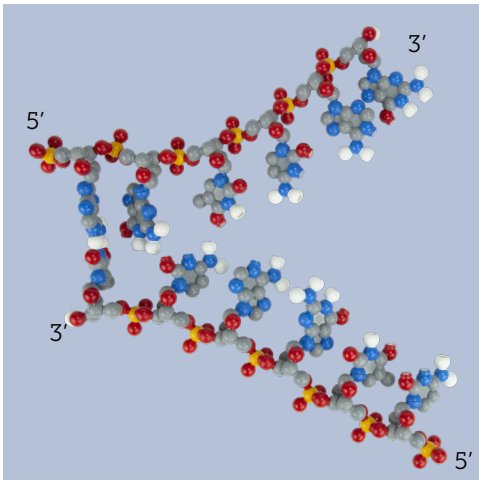
Untwist the DNA double helix.

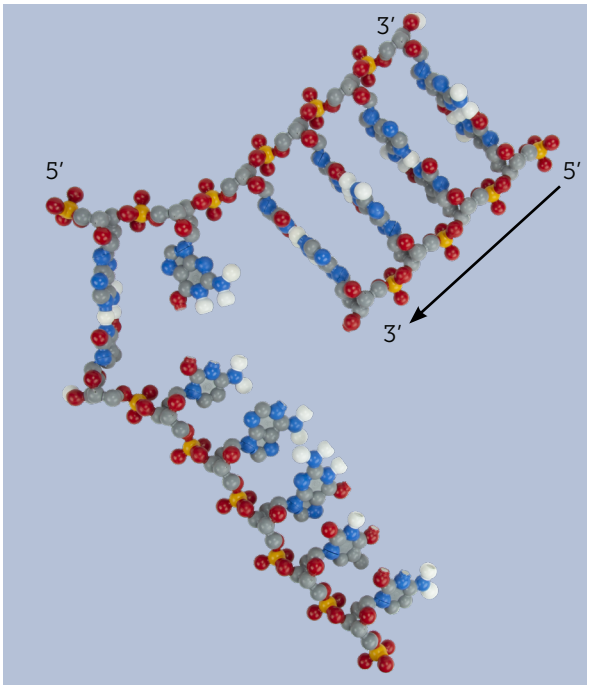


Separate the two strands to form a replication fork.

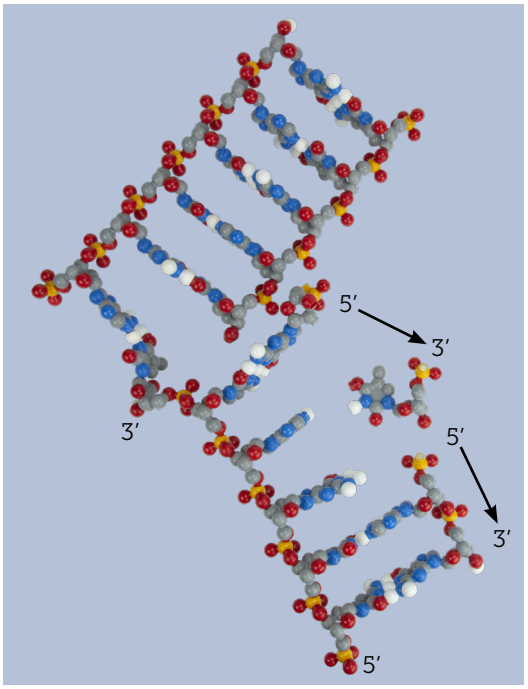


New DNA strands are synthesized in the 5' → 3' direction. Due to the anti-parallel nature of DNA structure, one strand will be synthesized *continuously* while the opposite strand will be synthesized in short fragments (Okazaki fragments).

Continuous Replication



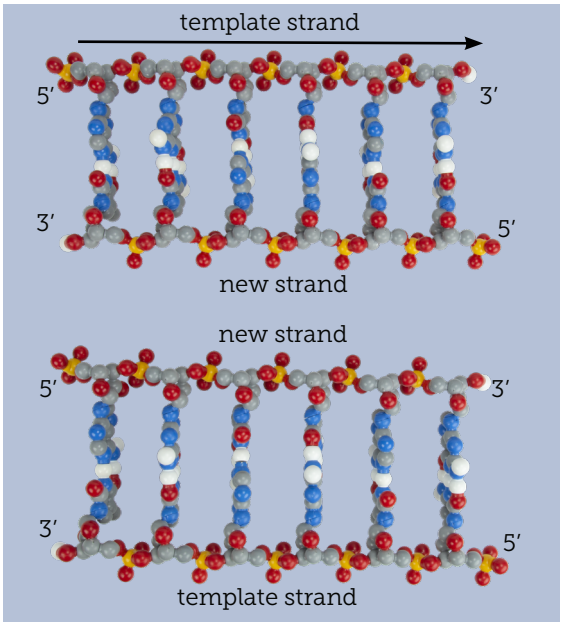
Discontinuous Replication



Note: Both strands replicate simultaneously. They are shown separately for clarity.

Teacher Guide

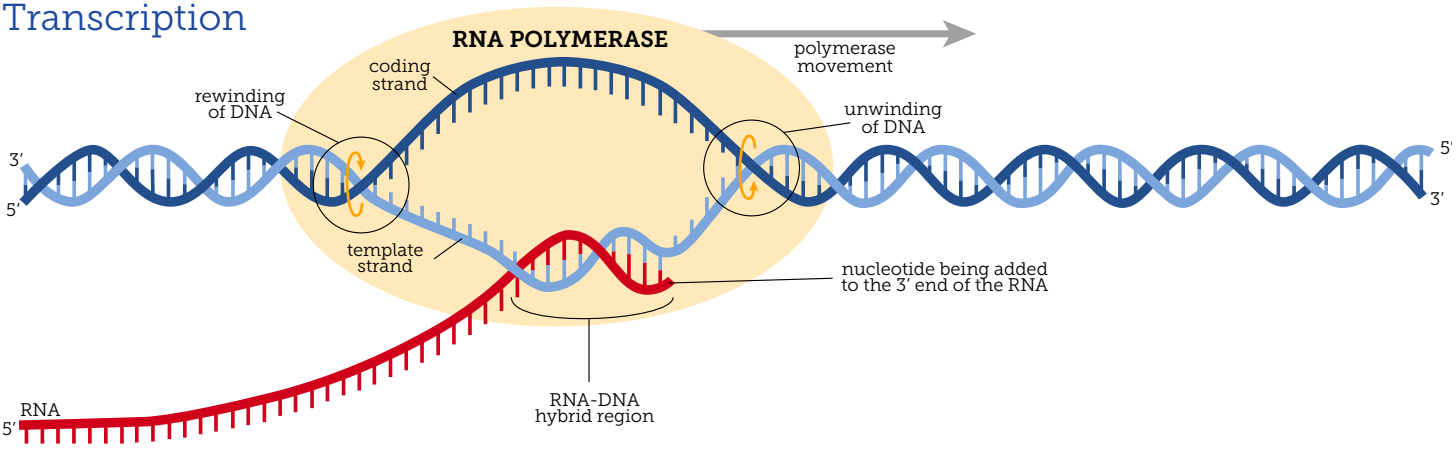
Semiconservatively Replicated DNA



Going Further with Replication . . . .

- If 3 or more *Dynamic DNA Kits*© are available, create a replication bubble to model DNA replication.
- Model Meselson and Stahl's experiment to support the semiconservative model of DNA replication. Please see *Flow of Genetic Information Kit*© Replication Instructions (3dmoleculardesigns.com/Teacher-Resources/Flow-of-Genetic-Information-Kit/Replication-Student-Handout-and-Key.htm).
- Include the use of ribonucleotides to model the RNA primers needed to initiate DNA synthesis.
- Consider the need for topoisomerase to relieve the over-winding of the double helix that would result from the advancing replication fork.

Transcription



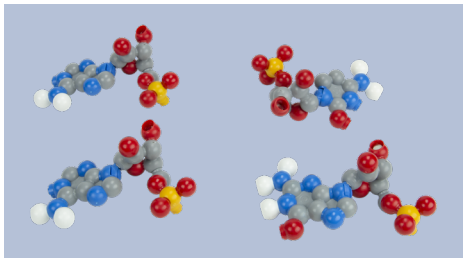
DNA inherited by an organism leads to specific characteristics determined by the synthesis of proteins from RNA molecules. **This flow of genetic information from DNA to RNA to protein is a central principle in biology**.

Teacher Guide

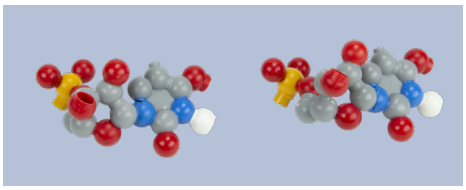
Transcription is the synthesis of RNA using the information stored in the DNA. To teach 3-dimensional aspects of **RNA transcription** using one 12 base pair set of *Dynamic DNA*©, we suggest that you use the following DNA sequence:

5’	**C**	**A**	**T**	**G**	**C**	**A**	**T**	**G**	**C**	3’	Template (coding)
3’	**G**	**T**	**A**	**C**	**G**	**T**	**A**	**C**	**G**	5’	Nontemplate (noncoding)

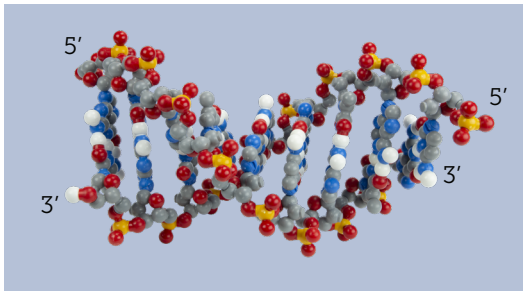
Before you begin the transcription process, convert two adenine (A) nucleotides, one guanine (G) nucleotide and one cytosine (C) nucleotide into the corresponding RNA nucleotides by adding an oxygen to the 2’ carbon of the sugar. Set these pieces aside. Refer to the assembly instructions if you need directions.



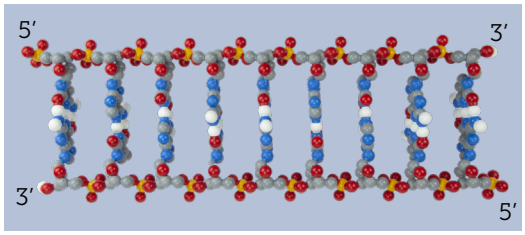
Convert two thymine (T) nucleotides into uracil (U) nucleotides by removing the methyl group from the fifth position in the nitrogen ring and adding an oxygen to the 2’ carbon of the sugar. Set these pieces aside. Refer to the assembly instructions if you need directions.



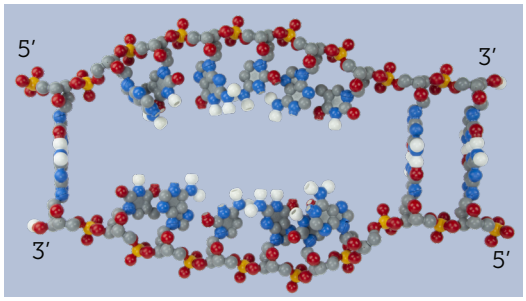
Assemble 9 DNA base pairs to form a double helix using the suggested sequence above. You will use the remaining 6 converted nucleotides to form the messenger RNA.



Untwist the DNA double helix.



Separate the two strands, keeping the first base pair together and the last two base pairs together.



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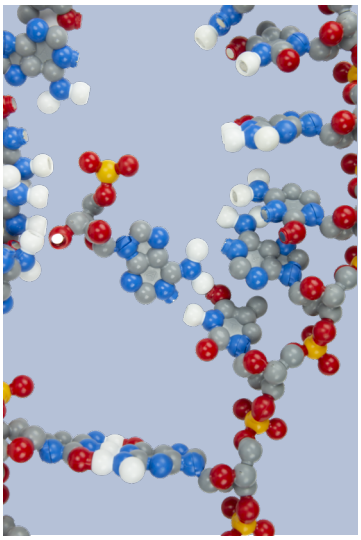
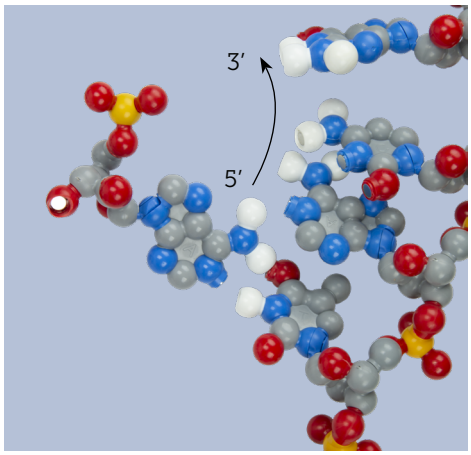
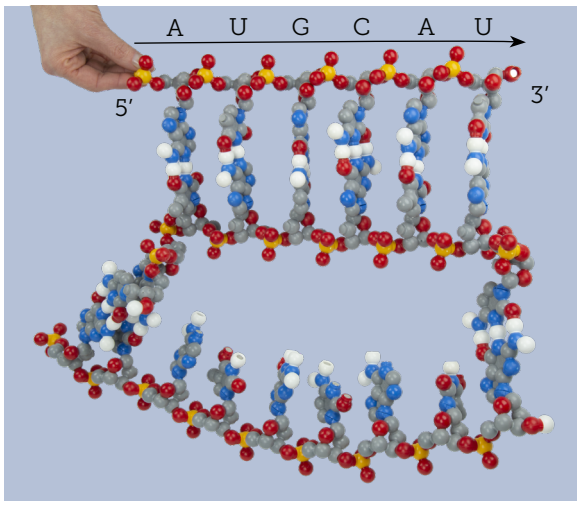


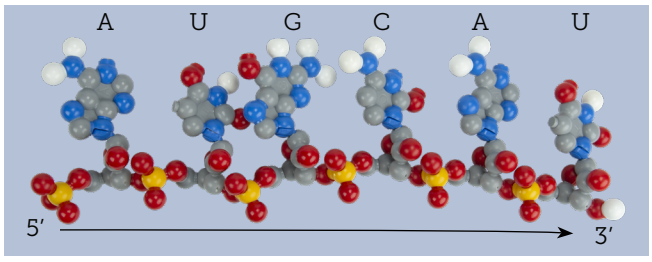
Students act out the role of RNA polymerase, which binds to the template strand of the DNA, to begin synthesis of mRNA that is complementary and anti-parallel to the DNA template strand. Keep in mind that mRNA is synthesized from its 5' → 3' end beginning with the start codon AUG.



Continue adding the complementary RNA nucleotides.



A newly synthesized mRNA is 6 nucleotides in length. Be sure to cap the phosphate and hydroxyl ends.



Going Further with Transcription . . . .

- Consider how the RNA polymerase *knows* which strand, and *in what* direction, to copy the DNA message.
- Investigate RNA processing:
  - How are the two ends of the mRNA protected from degradation by exonucleases that would otherwise shorten the lifetime of the mRNA?
  - How can the mRNA be modified through splicing?
  - Keeping splicing in mind, how might the discrepancy between the number of human protein-coding genes (about 25,000) and the 100,000 different proteins made by human cells be explained?

Teacher Guide

MODELING BIOINFORMATICS

The 21st century ushered in the sequencing of the human genome, which sparked a firestorm of remarkable advances in biotechnology. As informed citizens, students should be introduced to the new fields of **genomics** and **bioinformatics**.

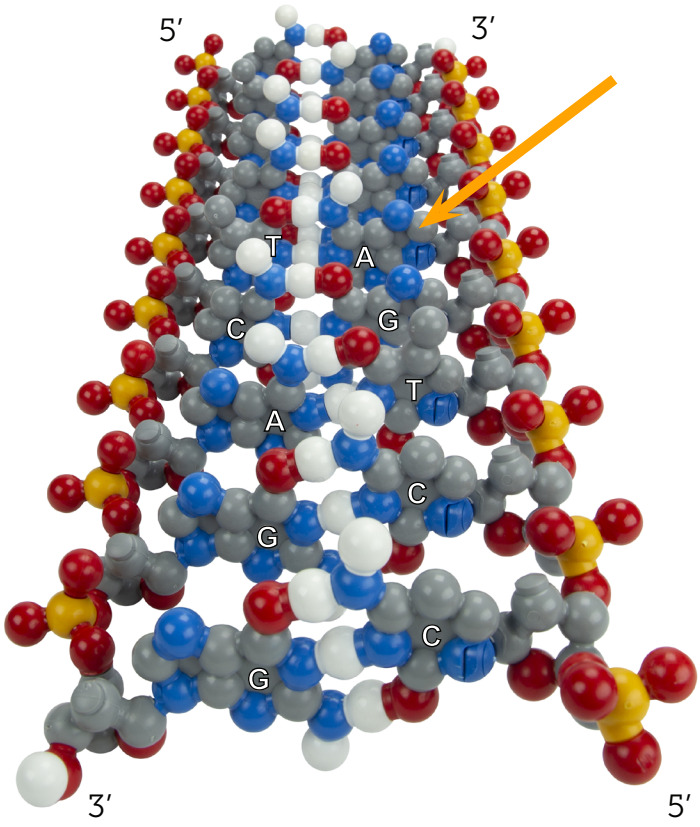
Untwist 12 base pairs of *Dynamic DNA*© into a flat, 2-dimensional ladder for students to easily read and model specific nucleotide sequences of important genes. Students could study the nucleotide sequence around the point where a mutation occurs in the beta globin gene that causes sickle cell anemia. Note that only a single base pair change results in this condition.*

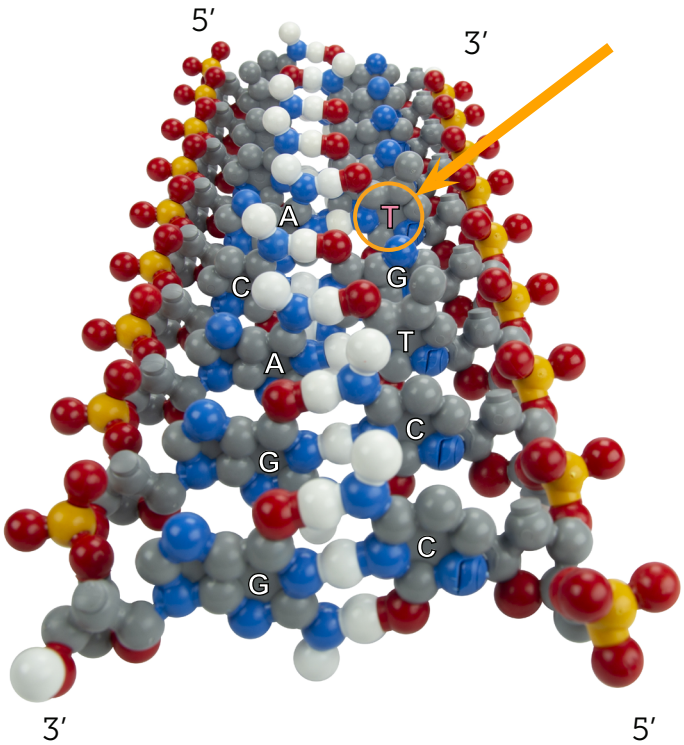
Normal DNA Nucleotide Sequence

5’	C	C	T	G	A	G	G	A	G	3’
3’	G	G	A	C	T	C	C	T	C	5’

Sickle Cell DNA Nucleotide Sequence

5’	C	C	T	G	T	G	G	A	G	3’
3’	G	G	A	C	A	C	C	T	C	5’





*The nucleotides in the kit have embossed letters. We added letters to the photos for clarity.

Use the kit to model how the CRISPR Cas9 protein could bind to a specific DNA sequence. Separate the two DNA strands, form complementary base pairs between its guide RNA and one strand of DNA and then cut the DNA to initiate a gene editing event.

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NEXT GENERATION SCIENCE STANDARD FRAMEWORK CONNECTIONS

SEPs	CCCs	DCIs
Asking Questions	Patterns	PS1: Matter and Its Interactions
Developing and Using Models	Cause and Effect: Mechanism and Explanation	LS1: From Molecules to Organisms: Structures and Processes
Constructing Explanations and Designing Solutions	Scale, Proportion, and Quantity	LS3: Heredity: Inheritance and Variation of Traits
Analyzing and Interpreting Data	Structure and Function	LS4: Biological Evolution: Unity and Diversity
Engaging in Argument from Evidence	Stability and Change	ETS2: Links Among Engineering, Technology, Science, and Society