What If? A World Without Code — DNA

Secrets of the Sequence Video Series on the Life Sciences • Grades 9 — 12

Teaching materials developed by **VCU** Life Sciences

Virginia Commonwealth University

For Classroom Trial Testing

Video Description

"Secrets of the Sequence," Show 148, Episode 1

"What If? A World without Code"–approximately 9 minutes viewing time

James Watson and Francis Crick, the co-discoverers of the DNA double helix, changed the world forever when they unveiled their now familiar molecular model fifty years ago. Utilizing data from previous biological research, Watson and Crick conceived a beautiful structure that explained how living things grow. Renowned geneticists and researchers discuss the significance of the double helix and pay tribute to its inventors, as well as ponder where we might be without this fundamental research.

Ward Television
Producer: Paul Gasek
Associate Producer: Teri Prestholdt
Featuring: Rudolf Jaenisch, Founding Member, Whitehead Institute; David Page, Associate Director, Whitehead Institute; Phil Leder, Harvard Medical School, Howard Hughes Medical Institute; Mark Daly, Computational Biology, Center for Genome Research; Mark Kershner, Cell Biology, Harvard Medical School; David Altshuler, Center for Genome Research, Harvard Medical School
Lesson Author; Reviewers: Elizabeth Armstrong; Catherine Dahl, Dick Rezba, and Selvi Sriranganathan
Trial Testing Teachers: Raananna Bayliss, Martin Shields

National and State Science Standards of Learning

National Science Education Standards Connection

Content Standard A: Science As Inquiry

As a result of their activities in grades 9 - 12, all students should develop an understanding about scientific inquiry.

Content Standard C: Life Science

As a result of their activities in grades 9 - 12, all students should develop an understanding of:

- The Molecular Basis of Heredity
- Biological Evolution

Content Standard E: Science and Technology

As a result of their activities in grades 9 - 12, all students should develop an understanding about science and technology.

Content Standard F: Science in Personal and Social Perspectives

As a result of their activities in grades 9 - 12, all students should develop an understanding of:

- Science and technology on local, national, and global challenges

Content Standard G: History and Nature of Science

As a result of their activities in grades 9 - 12, all students should develop an understanding of:

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

Selected State Science Standards Connections

Use http://www.eduhound.com (click on "Standards by State") or a search engine to access additional state science standards.

Virginia

BIO.2 The student will investigate and understand the history of biological concepts. Key concepts include

c) evidence supporting the cell theory;
d) development of the structural model of DNA; and
e) the collaborative efforts of scientists, past and present.

BIO.6 The student will investigate and understand common mechanisms of inheritance and protein synthesis. Key concepts include

d) cell growth and division;
e) genetic variation (mutation, recombination, deletions, additions to DNA);
f) the structure, function, and replication of nucleic acids (DNA and RNA);

BIO 7 The student will investigate and understand bases for modern classification systems. Key concepts include

d) examination of biochemical similarities and differences among organisms

Florida

The Nature of Science

Standard 1: The student uses the scientific processes and habits of mind to solve problems. (SC.H.1.4)

1. knows investigations are conducted to explore new phenomena, to check on previous results, to test how well a theory predicts, and to compare different theories.
2. knows from time to time, major shifts occur in the scientific view of how the world works, but that more often the changes that take place in the body of scientific knowledge are small modifications of prior knowledge.

Standard 2: The student understands that most natural events occur in comprehensible, consistent patterns. (SC.H.2.4)

1. knows that scientists assume that the universe is a vast system in which basic rules exist that may range from very simple to extremely complex, but that scientists operate on the belief that the rules can be discovered by careful, systemic study.

Standard 3: The student understands that science, technology, and society are interwoven and interdependent. (SC.H.3.4)

2. knows that technological problems often create a demand for new scientific knowledge and that new technologies make it possible for scientists to extend their research in a way that advances science.
3. knows that scientists can bring information, insights, and analytical skills to matters of public concern and help people understand the possible causes and effects of events.
6. knows that scientific knowledge is used by those who engage in design and technology to solve practical problems, taking human values and limitations into account.

Overview

This lesson teaches students about the discovery of the structure of DNA and the importance of this knowledge in science today. Watson and Crick saw the structure of the DNA molecule as a double helix, often referred to as a twisted ladder, composed of two single-strands of DNA held together by hydrogen bonds between the complementary bases A-T and G-C. This immediately suggested to them a mechanism for DNA duplication; the paired strands, once separated, could provide templates to make new strands of DNA identical to the original twisted ladder. The structure and the copying mechanism it suggested also offered an explanation for how mutations could occur in DNA – occasional errors in copying a template could lead to altered base pairs.

The structure of DNA explains how inheritance works – which is a fundamental question for scientists. In addition, it offers understanding into the genetic bases of diseases and other mutations. Students will investigate the structure of DNA in the student activity and work through the process of replication, transcription and translation.

Testing: A sample related multiple choice item from State Standardized Exams

If a portion of a DNA strand has the base sequence TACGCA, what will be the base sequence of the mRNA strand transcribed?

- TACGCA
- UACGCA
- AUGCGU*
- ATGCGT

Source: North Carolina, Biology Sample Items

Video Preparation

Preview the video and make note of the locations at which you will later pause the video for discussion.

Before Viewing

1. Ask a student to look up the definitions of *iconic and icon*. You will need this later.
   Pertaining to or having the character of an icon. An icon is something devotedly admired, something that is revered.

2. Ask: "Who were Francis Crick and James Watson?" You may need to repeat their names as Crick and Watson or as Watson and Crick.
   Students may identify them as the men who discovered DNA, which is not correct. Some may say they discovered the double helix. Ask for further explanation. Watson and Crick discovered the ***structure*** *of the DNA molecule, which turns out to be a double helix, often described as a twisted ladder.*

3. Review the following terms with the students and record on the board. Review how base pairs match up (A to T, C to G).

   - Purines (*nitrogenous bases* made of two rings*)
   - Pyrimidines (*nitrogenous bases* made of one ring*)
   - Adenine *(a purine that bonds with thymine*)
   - Thymine (*a pyrimidine that bonds with adenine*)
   - Guanine (*a purine that bonds with cytosine*)
   - Cytosine (*a pyrmidine that bonds with guanine*)

   ** basic, nitrogen-containing molecules*

4. While watching the video, have students make a list of things that we take for granted about heredity and molecular biology that would not be possible if we had no knowledge of DNA or its structure.

During Viewing

1. START the video.

2. PAUSE (about 5:46 minutes in the video) after the scientist, Mark Kershner, says, "… how could it not have been discovered."

   Ask: "What did he mean by saying that the discovery of the double helix is the 'bedrock of all biology?' " Given the fundamental importance of understanding our heredity, what other major discoveries do you think compare to the discovery of the double helix?

   He meant that our understanding of how DNA is stored and transmitted between generations is crucial to our understanding of how it affects how we live, grow, reproduce, and eventually die. Some other major discoveries include:

   - *The world is round, not flat*
   - *The earth revolves around the sun*
   - *Fire*
   - *Newton's laws of gravity*
   - *Periodic table*
   - *Nuclear physics*

3. RESUME the video and play to the end.

After Viewing

1. Have a student read the definition of "iconic".

2. Ask: "In what way was the structure of DNA an iconic discovery? "
   Student answers may vary – an example is that it answers the age old question about heredity and shows us that the vast majority of our DNA is similar, i.e. all humans are essentially the same. Except for minute differences, our genetic codes are identical. However, it is the small but significant differences in DNA that make us the individuals who we are.

3. Discuss the students' list of things that we take for granted every day that would not be possible if we had no knowledge of DNA or its structure.
   Responses may include:
   - *there would be no genetic testing (for instance, familial deafness, Tay-Sachs, Huntington's disease, multiple sclerosis, and paternity/maternity testing)*
   - *no genetic engineering to improve crop production*
   - *no benefit of recombinant DNA, which allows for the mass production of insulin and many vaccine serums*
   - *no understanding of the fundamentals of the functioning of DNA that all present cancer research relies upon*

4. Ask: "How does the structure of the double helix ensure that all cells of any organism get the same genetic code?"
   Note: This answer is not stated outright in the video, but it is implied. Students may need some guidance or a hint.
   The specificity of base-pairing (e.g. A-T and G-C pairs only) suggests a semi-conservative method of

replication. That is, the two strands of DNA can separate and each act as a template for the formation of a new strand. Because of the specificity of base-pairing, identical copies are guaranteed, barring any errors in replication (which are extremely rare events) such that all cells would get the same genetic code.

5. Conduct the Student Activity: Cracking the Code

Teacher Notes for the Student Activity: Cracking the Code

Distribute copies of the Student Handout: Cracking the Code and Appendix A: Table of Codons to each student or pair of students. Read through the procedure with the students. The activity consists of two parts:

Part A: From DNA to DNA: Replication
Part B: From DNA to RNA to Protein: Transcription and Translation.

Note: You may wish to review the specific structures and functions of DNA, mRNA, and tRNA with your class. The necessary background information is given at the top of the student handout. For further information on the structure of DNA or clarification through visuals, you may want to visit some of the Web sites listed in 'Additional Resources' at the end of this lesson. Also if any terms are unfamiliar to the students, you may want to have them "Google" the term.

Part A: From DNA to DNA: Replication

Introduction: Review Questions

Ask students the following:

1. In what part of the cell is DNA found?
   In eukaryotic cells, it is in the nucleus and mitochondria and (plants only) in chloroplasts.
2. What are the units (building blocks) of DNA called?
   Nucleotides
3. Those units are composed of what three parts?
   Sugar, phosphate, nitrogen base
4. What are the two types of bases?
   Purine and pyrimidine
5. Which nitrogenous base is composed of one ring?
   Pyrimidine
6. Which nitrogenous base is composed of two rings?
   Purine

Procedure: Activity Questions

Have students quickly review how bases match up before creating a complementary strand to the given template strand and then answer the questions based on this exercise.

1. Quick review: Adenine bonds with _____ (A to ___); Cytosine bonds with _____ (C to ___)

   Adenine bonds with thymine (A to T); Cytosine bonds with guanine (C to G)

Now have the students complete Table 1 with the complementary bases starting with the 3' end of the template strand. When they have finished, they will have created the complement strand or daughter strand.

TABLE 1: Answer Key
DNA to DNA: Replication

3’	5’
Template Strand	Complementary Strand
T	A
A	T
C	G
T	A
C	G
A	T
C	G
A	T
T	A
C	G
G	C
C	G
C	G
T	A
C	G
G	C
C	G
A	T
A	T
T	A
T	A
5’	3’

If necessary explain to students what it means to “read a template from 3’ to 5’ (3 prime to 5 prime). It is essential to understand that DNA is a 2-stranded molecule and the 2 strands run antiparallel such that one strand runs 3’ to 5’ while the other runs 5’ to 3’. Replication always ‘begins from’ or extends the 3’ hydroxyl so the complementary strand or new daughter strand begins with its 5’ hydroxyl and is built from 5’ to 3’. In other words, the template is “read” from 3’ to 5’ while the complementary strand is “built” from 5’ to 3’.

2. In the future when this double strand of DNA undergoes replication itself, which will be the parent or template strand?
   In the next round of replication, both strands will act as templates.

3. If you were to use the strand you created as a template, what would you create? Explain why this is important in cell division.
   If you were to use the complementary strand as a template, replication would produce a strand with a sequence identical to our original template strand. Thus, semi-conservative replication constantly recreates the same sequence over and over again. This is important in cell division to ensure that the genetic code is faithfully transmitted generation after generation.

Part B: From DNA to RNA to Protein: Transcription and Translation

Introduction: Review Questions
Ask students the following:

1. What are the types of RNA involved in protein synthesis?
   - *Messenger RNA (mRNA)*
   - *Transfer RNA (tRNA)*
   - *Ribosomal RNA (rRNA)*
2. RNA is different from DNA in that it contains a different form of sugar. It still has the three main components of a nucleotide. What are those three components?
   - *Sugar*
   - *Phosphate*
   - *Nitrogen base*
3. RNA does not contain the base thymine; it is replaced by uracil.

   - What RNA base bonds to Adenine on DNA?
     Uracil
   - What does Cytosine bond to?
     Guanine

Procedure:

1. Transcription: Tell students to complete the second column of Table 2 below. Working from the 3' end of the template, write in the matching bases for the RNA; don't forget about uracil. RNA that uses DNA as a template is called messenger RNA, or mRNA.
   a. In what parts of the cell is messenger RNA found?
      Messenger RNA (mRNA) is predominantly found in the nucleus and in the ribosomes
   b. What is the purpose of messenger RNA?
      Its function is to act as an intermediate between DNA and protein

2. Translation: Tell students to use the Table of Codons in Appendix A to determine the appropriate amino acids.

   Note: Question 3 may be difficult for the students to answer but let them make an attempt before giving the full explanation below.

3. Do you know what the vital function of tRNA is in creating these proteins? In what part of the cell is tRNA?
   Transfer RNA or tRNA brings amino acids to the ribosomes so that mRNA can be translated. tRNA matches up with the RNA through base pairing. While 3 mRNA bases form a codon, each of these mRNA codons match up to one of 20 different tRNA molecules, each with a 3 base "anticodon" at one end and carrying a specific amino acid at the other end. In this way tRNA molecules act as adapters to read

codons in mRNA and insert the correct amino acid into the growing protein. It is this codon to aniticodon matching process that explains why the genetic code is exactly as shown in the Table of Codons in Appendix A. The tRNA is found throughout the cell cytoplasm.

TABLE 2: Answer Key
DNA to RNA to Protein: Translation and Transcription

3’	5’	
Template Strand	mRNA Strand	Amino Acid
T	A	MET (START)
A	U	
C	G	
T	A	SER
C	G	
A	U	
C	G	VAL
A	U	
T	A	
C	G	ALA
G	C	
C	G	
C	G	GLU
T	A	
C	G	
G	C	ARG
C	G	
A	U	
A	U	STOP
T	A	
T	A	
5’	3’	

Note: You may wish to have students grade each other’s papers, to both save time and to make a point about the necessity of “proof reading” mechanisms of DNA repair in order to preserve fidelity of transmission. In other words, before replication is truly finished another enzyme double-checks the base-pairing of the DNA and corrects any discrepancies it finds. The students act as each other’s DNA repair enzymes, double checking the duplication and transcription of their classmates.

Student Handout: Cracking the Code

Background:

DNA is the blueprint for life – each cell in our body must have a copy of our DNA in order to fulfill its purpose. DNA is transmitted faithfully when cells multiply in a process known as *semi-conservative replication*. The two strands of DNA separate and each acts as a template for the synthesis (or replication) of a new strand. New bases are paired with the template strand, and are then connected to one another to form a new strand of DNA.

DNA regulates cellular function by directing the creation of certain proteins. It acts as a model for making a molecule similar to itself called *messenger RNA* (mRNA). This process is known as transcription and functions in a manner similar to DNA replication. The only difference is that instead of the entire molecule of DNA being copied, individual genes are transcribed into mRNA molecules. Additionally, multiple mRNA copies of a single gene can be made at the same time. After mRNA is formed, it leaves the nucleus and attaches to a ribosome. Other RNA molecules (*transfer RNA*, or tRNA) bring amino acids to the ribosome. The mRNA and tRNA match up and the amino acids are linked to build a protein.

Part A: From DNA to DNA: Replication

Introduction: Review Questions

1. In what part of the cell is DNA found?

2. What are the units of DNA called?

3. Those units are composed of what three parts?

4. What are the two types of bases?

5. Which nitrogenous base is composed of one ring?

6. Which nitrogenous base is composed of two rings?

Procedure: Activity questions

You have two strands of DNA in Table 1 below; one has been completed, the other you will complete.
The strand on the left is the **template** or **parent** strand. The strand you will "create" is the **complementary** or **daughter** strand. Answer the following questions as you work through this section.

1. Quick review: Adenine bonds with _____ (A to ___); Cytosine bonds with _____ (C to ___)

Starting with the '3' end of the template strand write in the complementary bases. When you have finished, you will have created the complementary strand or daughter strand. Below the table is an explanation of "reading" from 3' to 5' and "building" from 5' to 3' which your teacher will discuss with you.

2. In the future when this double strand undergoes replication itself, which will be the parent or template strand?

3. If you were to use the strand you created as a template, what would you create? Explain why this is important in cell division.

TABLE 1:
DNA to DNA: Replication

3’	5’
Template Strand	Complementary Strand
T	
A	
C	
T	
C	
A	
C	
A	
T	
C	
G	
C	
C	
T	
C	
G	
C	
A	
A	
T	
T	
5’	3’

Note:
It is essential to understand that DNA is a 2-stranded molecule and the 2 strands run antiparallel such that one strand runs 3’ to 5’ (3 prime to 5 prime) while the other runs 5’ to 3’. Replication always ‘begins from’ or extends the 3’ hydroxyl so the complementary strand or new daughter strand begins with its 5’ hydroxyl and is built from 5’ to 3’. In other words, the template is “read” from 3’ to 5’ while the complementary strand is “built” from 5’ to 3’.

Part B: From DNA to RNA to protein: Transcription and Translation

Introduction: Review Questions

1. What are the types of RNA involved in protein synthesis?

2. RNA is different from DNA in that it contains a different form of sugar. It still has the three main components of a nucleotide. What are those three components?

3. RNA does not contain the base thymine; it is replaced by uracil.

   - What RNA base bonds to Adenine on DNA?

   - What does Cytosine bond to?

Procedure: Activity Questions

1. Working from the 3' end in Table 2 below, write in the matching bases for the RNA; don't forget about uracil. RNA that uses DNA as a template is called messenger RNA, or mRNA.
   - In what parts of the cell is messenger RNA found? _____

   - What is the purpose of messenger RNA? _____

2. Use the Table of Codons in Appendix A to translate the mRNA strand you have just built. Write the amino acids in the appropriate boxes in Table 2.

   Note: Every three mRNA bases are grouped together to form a codon. Each codon is matched to their appropriate amino acid in the Table of Codons. When amino acids are bonded together, they form proteins. Congratulation! You have created a protein.

3. Do you know what the vital function of tRNA is creating these proteins? In what part of the cell is tRNA found?

Table 2
Transcription and Translation Table

3’	5’	
Template Strand	mRNA Strand	Amino Acid
T		
A		
C		
T		
C		
A		
C		
A		
T		
C		
G		
C		
C		
T		
C		
G		
C		
A		
A		
T		
T		
5’	3’	

APPENDIX A:
Table of Codons

2nd Base → / 1st Base ↓	U	C	A	G	3rd base ↓
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
	UUA Leu	UCA Ser	UAA Stop	UGA Stop	A
	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
	CUC Leu	CCC Pro	CAC His	CGC Arg	C
	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
	AUG Met	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

Adapted from http://dl.clackamas.cc.or.us/ch106-09/translat.htm

Additional Resources

Because Web sites frequently change, some of these resources may no longer be available. Use a search engine and related key words to locate new Web sites

http://www.dnalc.org/ The Dolan DNA Learning Center (DNALC) is the world's first science center devoted entirely to public genetics education and is an operating unit of Cold Spring Harbor Laboratory, an important center for molecular genetics research.

http://www.dnaftb.org/dnaftb/ *DNA from the Beginning* is organized around key concepts. The science behind each concept is explained by: animation, image gallery, video interviews, problem, biographies, and links.

http://library.thinkquest.org/19037/dna_extraction.html?tqskip1=1&tqtime=1119
The purpose of this lab is to extract DNA from a variety of cells and see DNA molecules. This lesson shows that DNA is found in a variety of tissues.

http://www.sciencenetlinks.com/lessons.cfm?BenchmarkID=5&DocID=98
This site develops understanding of DNA by modeling the process of DNA extraction.
(Detailed description of the procedure used in the laboratory activity above.)

http://www.biorad.com Life Science Education. DNA extraction kit #166-2300 Edu. Genes in a Bottle.

DNA Is Here to Stay, by Dr. Fran Balkwill. 1992. ISBN # 0-00-191165-1 (Ages 9-15)

Genomic Revolution
http://www.ornl.gov/sci/techresources/Human_Genome/education/education.shtmL
This Web site of the government-funded Human Genome Project has links about genomics, the history of the project, and more.

Secrets of the Sequence Videos and Lessons
This video and 49 others with their accompanying lessons are available *at no charge* from www.vcu.edu/lifesci/sosq