The Secret of Life — Discovery of DNA Structure

Secrets of the Sequence Video Series on the Life Sciences • Grades 9 — 12
Teaching materials developed by **VCU** Life Sciences

Virginia Commonwealth University

Classroom Tested Lesson

Video Description

"Secrets of the Sequence," Show 149, Episode 1
"The Secret of Life – Discovery of DNA Structure" approximately 9 minutes viewing time

Fifty years ago, James Watson and Francis Crick announced to patrons in a Cambridge pub that they had just discovered the secret of life. Their discovery was that the DNA double helix explained how cells divide and develop. Yet it was not enlightened genius alone that propelled Watson and Crick toward this fundamental revelation. In addition they were building on the work of other scientists and a fortuitous (and un-acknowledged at the time) collaboration with Rosalind Franklin, a British X-ray crystallographer, who was of crucial help in this great achievement.

Ward Television
Producer: Paul Gasek
Associate Producer: Teri Prestholdt
Featuring: Eric Lander, Whitehead Institute, MIT Center for Genome Research
Lesson Author; Reviewers: Ellen Lamb, Lynn Visone; Catherine Dahl, Dick Rezba, Selvi Sriranganathan
Trial Testing Teachers: Regina Ahmann, Mike Comet, Bertha Tracy, Amanda Stewart

National and State Science Standards of Learning

National Science Education Standards Connection

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science

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

- The Cell
- Molecular basis of heredity

Content Standard G: History and the Nature of Science

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

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) prediction of inheritance of traits based on the laws of heredity
e) effects of genetic recombination and mutation

Delaware

Science as Inquiry

Scientific investigations in many cases follow no fixed set of steps. However, there are certain features of a valid scientific investigation that are essential and result in evidence that can be used to construct explanations. Tools and technologies extend human capabilities to perform investigations in more details and with greater accuracy and improved precision.

Science, Technology and Society

The practice of science and technology is not a linear process. In many cases, the desire of scientists to find what is real in nature creates opportunities for technology development. At the same time, technology provides scientists with tools and techniques that allow expansion of their capabilities and effectiveness.

History and Context of Science

Science is an international activity in which significant inventions and innovations have come from around the world. Even though scientists live and work in different cultures and come from different backgrounds, many of their activities are part of international collaborative efforts, and the knowledge created is shared in order to maximize the benefits to society.

Overview

This video highlights what many consider to be the most important discovery of the twentieth century. Francis Crick and James Watson, an unlikely pair to be studying the structure of DNA in the 1950's, used images produced by a British X-ray crystallographer, Rosalind Franklin, to determine exactly what that structure was – a double helix. Watson and Crick recognized immediately the importance of their discovery and the impact it was likely to have on the scientific community. Indeed, their work has led directly to the now commonplace technology of DNA manipulation with its multiple uses. Science took an enormous step forward with this new understanding of the double helix structure of DNA. Unlike many earlier discoveries made by individual scientific giants such as Albert Einstein, this work and most successful research today has been accomplished through the efforts of many scientists working on parallel problems.

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

Which DNA strand (reading down) below represents the complementary base sequence to the portion of a DNA strand represented below at the far left?

A	G	T	T	C
T	C	A	T	A
C	A	G	G	T
G	T	C	C	G
T	C	A	T	A
A	G	T	A	C
	(1)	(2)*	(3)	(4)

Source: New York Living Environment Regents Examination part A

Video Preparation

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

Note: This video makes reference to alcohol, specifically that Crick and Watson first announced their discovery over drinks at the local pub. This anecdote is meant to demonstrate what unlikely scientific heroes Watson (a 25 year old from Indiana) and Crick (from the U.K.) really were, not to promote the consumption of alcohol. If you believe it is necessary, you may address this issue either before or after showing the video to your class.

Before Viewing

1. Ask students: What do the names Francis Crick and James Watson mean to you? What about Rosalind Franklin or Linus Pauling?
   Francis Crick (who recently died in July 2004) and James Watson together changed the world with the most profound discovery of the 20th century – the determination of the structure of DNA – a double helix, which they called "the secret of life." Students may not have heard of Rosalind Franklin, whose practical work with X-ray crystallography provided the empirical support for the theoretical conceptions of Watson and Crick. Linus Pauling was a competitor of Crick and Watson, and he published a theoretical structure of DNA before *the famous duo – luckily for them, he was wrong.*

2. Ask: "What are some common uses of DNA technology today?"
   - *DNA evidence from crime scenes*
   - *genetic engineering of plants*
   - *cloning of research animals*
   - *genetic screening of individuals for hereditary diseases*
   - *paternity tests*

During Viewing

1. START the video.

2. PAUSE the video (2:31 minutes into the video) after the narrator says, "…could not have conceived their claims of the first human clone".
   Give the students an opportunity to share what they know about the topics mentioned:
   - bald mice
   - glowing mouse offspring
   - pesticide resistant crops
   - goats that produce spider silk in their milk
   - the OJ Simpson case
   - Dolly
   - Raëlians cloning humans.

   Note: You may want to conduct some research beforehand to become familiar with the advancements mentioned. There is also another *Secrets of the Sequence* video and lesson about goats producing spider silk called "Got Silk? – Biotech Applications."

3. PAUSE the video (7:19 minutes into the video) after Eric Lander, says "… it is perhaps more than anything the work of an extraordinary community that both cooperates and competes at the same time."

   Discuss why the discovery of the "secret of life" is a classic example of this form of scientific cooperation and competition.

   - *James Watson and Francis Crick were investigating the structure of DNA but were not experts in the field of X-ray crystallography. Crick was a physicist and Watson a Zoologist.*
   - *Linus Pauling, the leading authority on the structure of protein molecules at the time, theorized that DNA was a triple helix radiating around a sugar-phosphate backbone.*
   - *Rosalind Franklin, an expert in X-ray crystallography, took photographic images of DNA crystals with amazing clarity but she did not attempt to build models from her findings.*
   - *Watson and Crick saw those images and understood that they provided evidence that the structure of DNA was that of a double helix.*
   - *Watson and Crick immediately constructed a model to determine if their hypothesis was valid and thus the beginning of 20th century DNA technology began.*

4. RESUME the video and play to the end.

After Viewing

1. You many wish to play part of the 1987 movie about the discovery of the DNA structure, *The Race for the Double Helix*, with Jeff Goldblum (available from Amazon.com and other video sources).

2. Some of your students might enjoy reading the book, *The Double Helix* by James Watson. One trial tester suggested holding a raffle and giving away a copy of this book, which can be purchased quite inexpensively at most bookstores.

3. Conduct the student activity on constructing a double helix: *Making a Model of the DNA Molecule*

Teacher Notes for the Student Activity:
Making a Model of the DNA Molecule

In this activity the students will construct a model of the double helix DNA molecule. You will want to construct one first so that the students have a finished product to view and you can decide which materials work best for you.

Materials needed *

- Safety goggles (because of wire involved)
- Gloves (optional –small sharp wires can possibly cause cuts if not handled carefully)
- Plastic or paper plates or other containers such as Petri dishes to hold the beads
- Red beads (18 per student) and black beads (18 per student)
- Assorted glass tubular/bugle beads of four different colors and 2 lengths (each student will need 18 but give them approximately 20 in case they drop or lose one or two)
- 26 or 28 gauge floral wire (3 pieces of 45 cm [18 in.] long per student)

**Approximate costs for a class of 30 from Michaels® crafts stores:*

1 pkg. @$2.99	*8 mm faceted red beads (JC8233-30) 550 beads (enough for 1 class)*
1 pkg. @$2.99	*glass "E" black beads 6/0 (JC8180-11) 3 oz. (enough for 2-3 classes)*
1 pkg. @$2.99	*assorted glass bugle beads [3 sizes, 5, 10, 20 mm] (JC81883-123) 2 oz. (enough for 1- 2 classes though only 2 sizes are needed)*
1 roll @ $1.49	*floral stem wire 26 gauge, ¼ lb. (enough for at least 1 class) or*
1 wire packet @ $1.49	*floral stem wire 26 gauge precut into 40 pieces of 18 in. wire*

Materials available in most craft stores, such as Michaels®, Ben Franklin®, or Garden Ridge®; may also be available at Wal-Mart. It may also be less expensive to purchase beads from fishing supply catalogues rather than craft stores as they are used in making fishing lures.

If you cannot obtain floral stem wire, one trial tester suggested jewelry wire: 24 gauge for the backbone and 28 gauge for the base pairs.

Note: Using glass beads produces a good looking and durable DNA molecule. However, constructions using many other materials are available on the Internet including a less expensive alternative that uses either drinking straws or coffee stirrers of different colors, which are cut to the appropriate length. As an alternative to wire, use brightly colored pipe cleaners available at most craft stores.)

Preparation

1. You may want to count into small cups or plastic bags the 18 red and 18 black beads each student needs as opposed to giving them a whole packet. Alternatively, you could have the students prepare their own bag, either at the end of the previous class or at the beginning of this one.

2. A strip of duct tape over all sink drains before beginning this exercise may be helpful in preventing loss of materials or clogged drains during clean-up.

3. The bugle beads are probably best given to students as a packet to sort through. Each student will ultimately need about 20 including 4-5 long beads of one color, 4-5 long beads of a second color, 4-5 short beads of a third color and 4-5 short beads of a fourth color. Letting them sort and select the tubular/bugle beads will give students the maximum choices in constructing their double helix models

and save you a lot of time.

4. Each student will also need 3 pieces of wire. The 28 gauge wire, which is thinner, is easier to thread through the beads but it bends a bit too easily and may be sharp enough to cut, while the 26 gauge, which is thicker, can be a bit stiff but acts as a more sturdy support for the sugar phosphate backbone. The best gauge is determined by the beads you use; you may wish to try both sizes of wires to see which one you prefer. Either scissors or nail clippers work fine for cutting the wire. Caution students to be careful using the wire to prevent possible wire-cuts.

Procedure

1. Have the students decide as a group specific bead colors and sizes for all of the bases.
Purines (adenine and guanine) are the larger of the two types of bases found in DNA and are therefore represented by the longer bugle bead. The Pyrimidines are the shorter of the two bases and are represented by the shorter bugle beads.

Letter	Base name	Long or short bead	Bead Color
A	*Adenine*	*Long*	
G	*Guanine*	*Long*	
C	*Cytosine*	*Short*	
T	*Thymine*	*Short*	

2. Have students fill in the table below creating a 9 base pair sequence from which they will model their "DNA molecule". Note that when a DNA sequence is normally read, it is read downwards, with all the first letters of each pair in a column and all the 2nd letters of each pair in a corresponding column. The first base pair is given as an example.

Sequence of 9 base pairs (normally "read" downwards)

G - - C	--	--	--	--	--	--	--	--

3. Construct a model of the DNA molecule following the Steps and pictures in the Student Handout. You may find it useful to display these images on your classroom projector.

4. While each student will want to make their own model, some students may find it easier to work with a partner.
Note: One trial test teacher noted that a few students become frustrated working with the beads, but the majority finished the project within an hour and were excited when they did since they could then relate well to the actual double helix shape of DNA.

5. If time allows, you may wish to have students read the original published DNA article.

If the Internet is available, some students may be interested in reading the one page Nobel Prize Winning paper on DNA from Nature - April 1953. Available at:
http://biocrs.biomed.brown.edu/Books/Chapters/Ch%208/DH-Paper.html

The paper is also available at http://www.nature.com/nature/insights/6921.html) where it was re-published on the 50th anniversary of the discovery of the DNA structure. On this Web site, scroll down until you see the section called 'Original Papers'. Click on Watson and Crick's paper. You can also print copies of this PDF file if you wish.

Discussion

The following questions may be used as a basis for in-class discussion:

1. Why didn't a triple helix model work to explain DNA structure?
As stated in the video, a triple helix model supposed that three negatively-charged molecules would bind to each other, a physical impossibility.

2. What is the novel feature of the Watson - Crick Model?
Their double-helix model was theoretically valid and agreed with the X-ray crystallography conducted by Rosalind Franklin.

3. How does the sequence of one side of DNA determine the other side?
Complementary base-pairing between adenosine and thymine and between guanine and cytosine

4. What is a major significance of this specific structure?
This structure suggests a semi-conservative method of DNA replication – that is, each strand can serve as a template for the creation of a new DNA molecule.

5. Many biologists feel that the discovery of DNA structure is the most significant biological discovery of this century.

    - Why do they feel that the discovery of DNA structure was so significant?
    Knowing the structure of DNA was the first step in understanding its function as genetic material.

    - Do you agree?

    - Did Watson and Crick deserve the Nobel Prize? What about Franklin?

Optional Additional Activities

Activity A: If the Internet is available, direct the students to the Web site for DNA Interactive www.dnai.org/a/index.html and have them work through the interactive site called FINDING THE STRUCTURE. Students will explore the initial problem that the scientists faced as well as who was involved with this study. Following that they should watch the interviews with the individual scientists to understand their contributions to the puzzle that Watson and Crick were able to solve.

If the Internet is not available, give the students the handout on Finding the Structure (see Appendix A) that describes the contributions of Friedrich Meischer, Phoebus Levene, Oswald Avery, Erwin Chargoff, and Rosalind Franklin. Their work helped Watson and Crick solve the puzzle of DNA structure. Students should be able to answer the following questions after exploring the interactive site on the Internet or by reading the handout:

1. What was Miescher's contribution to our knowledge of DNA? *Meischer isolated the first crude extract of DNA*

2. What was Phoebus Levene's contribution to our knowledge of DNA? *Levene began deconstructing the DNA components. He found that DNA was essentially a long-chain molecule, made up of four different nucleotides, ribose sugar and phosphate.*

3. Why were scientists skeptical about DNA being the stuff of life? *How could only 4 different components really contain all the information necessary for the form and function of life?*

4. What did Oswald Avery's group show? *That DNA was the "transforming principle" and was carrying hereditary information.*

5. What did Chargoff contribute to solving the puzzle of the structure of DNA? *He saw there were constant quantities of nucleotides in a given DNA*

6. What tool did Franklin provide that enabled Watson and Crick to guess the structure? *X-ray crystallography*

DNA Interactive also offers a free DVD set, *Scanning Life's Matrix: Genes, Proteins, and Small Molecules*.

<u>Activity B:</u> One trial tester suggested having students cut out models of the nucleotides from cardboard to show how they bond and why Watson and Crick were successful in their model building. If each set of 2 base pairs is "hole-punched" in the middle and appropriately stacked with a string threading through in order to suspend the models, you can start to see the spiraling of the structure. Furthermore, you can have students "join" their models of DNA into a continuous strand and calculate what "percentage" of the length of the entire molecule (base pair wise) their class structure is. If the models are really good, they will recreate the spiraling of the structure, especially if you have many students doing it.

Student Handout: Making a Model of the DNA Molecule

In this activity you will construct a model of the double helix DNA molecule. Please read all of the steps of the procedure before beginning with Step 1. Study the example of the finished product so you know what your end result should look like.

Materials

1. Safety goggles (because of wire involved)
2. 1 Plastic or paper plate or other flat container to hold the beads
3. 18 red beads
4. 18 black beads
5. Assorted glass tubular or bugle beads in 4 colors and 2 lengths (approximately 20)
6. 3 pieces of 26-gauge floral wire (45 cm or 18 in. long)

Preparation

1. Obtain 18 red beads that will represent the sugar

2. Obtain 18 black beads that will represent the phosphates

3. Fill in the table below and use it as a guide to selecting the colors of the two sizes of bugle/tubular beads that you will need for building the rungs of the DNA ladder. *Use long beads to represent the purines and shorter beads to represent the pyrimidines.(Ask your teacher if you are not familiar with which are the purines and which are the pyrimidines)*

Letter	Base name	Long or short bead	Bead Color
A			
G			
C			
T			

4. Make up any 9 pairs of bases and record them in the table below. Remember, the bases can only combine in certain ways. Use the pairs you have chosen to construct your "DNA molecule". *Note: When a DNA sequence is normally read, it is read downwards, with all the first letters of each pair in a column and all the 2nd letters of each pair in a corresponding column. The first base pair is given as an example.*

Sequence of 9 base pairs (normally "read" downwards)

G - - C	--	--	--	--	--	--	--	--

5. Before starting construction, make sure you have the correct amount of colored tubular beads to match the sequence you have just created.

6. Obtain 3 strands of wire, each 45 cm (18 in.) long.

Procedure

Refer to the pictures of each step on the attached sheet.

Step 1. String 1 red bead onto 1 piece of wire. Fold the wire into a "U" so that the bead is at the bottom of the "U". Twist the wire twice just above the bead to hold it firmly in place.

Step 2. Repeat Step 1 with another piece of wire and a black bead.

Step 3. Take the two ends of the wire with the black bead on it and thread the two wires through a red bead, then another black, another red, and so on until you have an alternating string of 9 black and 9 red beads. Wrap some of the excess wire around your finger to temporarily create some loops that will prevent the beads from coming off.

Step 4. Now repeat Step 3 with the wire with the red bead on it until you have another alternating string of 9 black and 9 red beads. These beaded strings will be the sides of your DNA model representing alternating sugars (deoxyribose) and acids (phosphates). The larger red beads represent sugars, while the smaller black beads represent acids.

Step 5. To make the rungs of the ladder attach one end of a third piece of wire just above the bottom red bead on the string of beads that starts with a red bead.

Step 6. Looking at your sequence, pick out the appropriately matched 2 bugle beads , 1 short and 1 longer representing a base pair, and string them onto the wire to form the first rung. (Reminder: the long bugle beads represent the nitrogen bases, purines and the short bugle beads represent the pyrimidines.)

Step 7. Connect the two sides of the DNA model by attaching the wire to the other string of beads by threading the wire through the twisted loop just above the black bead at the bottom of the string of beads. Then thread the wire upward through the next two beads (1 red and 1 black).

Step 8. String 2 new bugle beads representing the 2nd base pair in your created sequence onto the wire to make the second rung. Attach this rung to the other side of the model by skipping two beads and threading the wire through the next two beads.

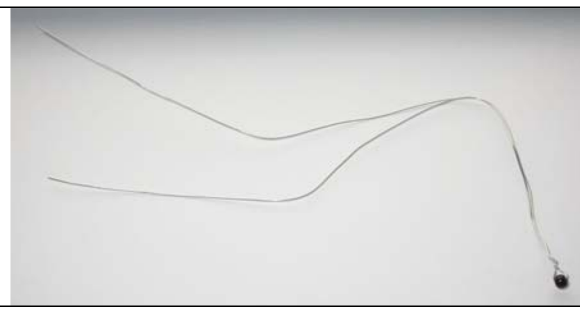
Step 9. Continue construction ensuring that each rung on the DNA ladder represents accurately your base pairs and by following the instructions in Step 8.

Step 10. When you have 9 rungs on your ladder, tie the wire ends into a loop. Twist the excess wire around and down each side of the loop until you reach the beads. Use scissors or a nail clipper to cut off any excess wire.

Step 11. Using two hands grasp the top and bottom of your model and gently twist to form a spiral ladder representing the double helix.

You have just created the double helix DNA molecule – the symbol of the 21st century revolution in cellular biology. Enjoy using it as a key chain or hanging ornament!

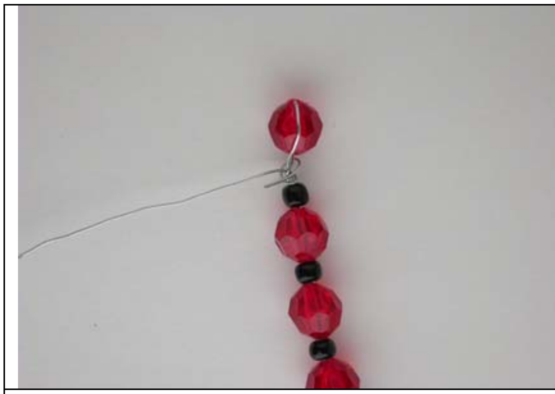
Step 1



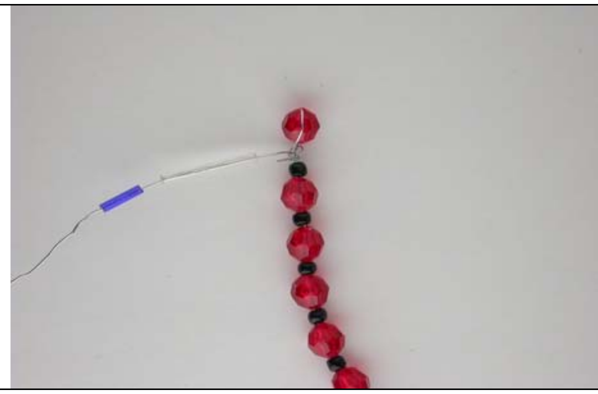
Step 2

Step 3

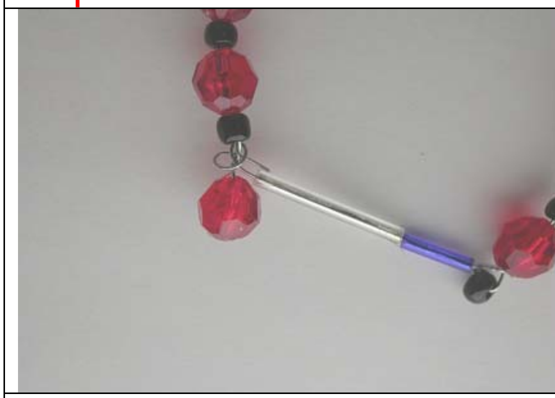
Step 4



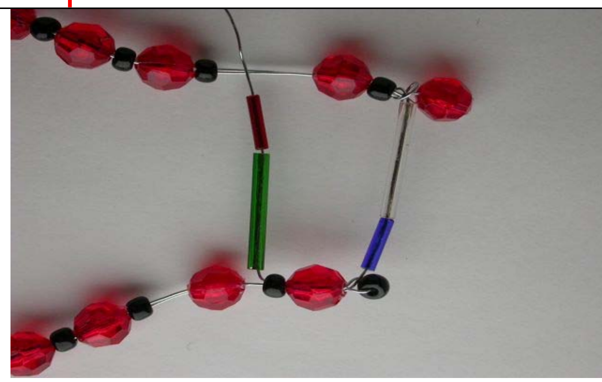
Step 5



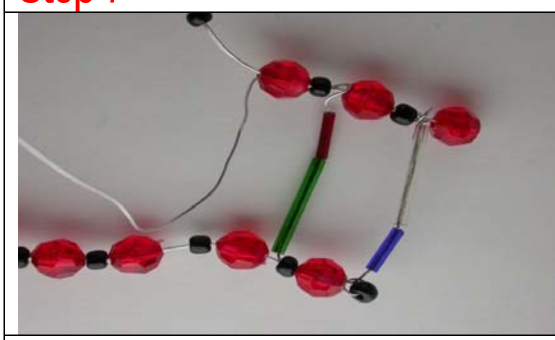
Step 6



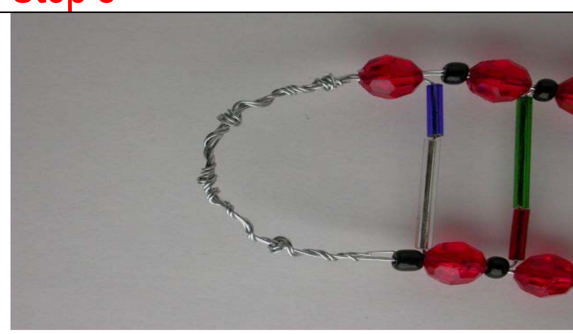
Step 7



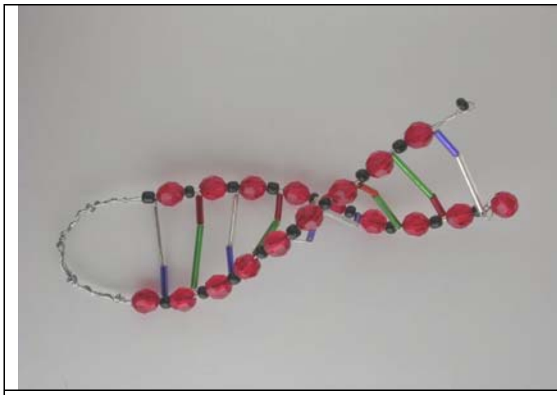
Step 8



Step 9



Step 10



Step 11

If the Internet is available, read the one page Nobel Prize Winning paper on DNA from Nature - April 1953. The paper is available at http://www.nature.com/nature/insights/6921.html) where it was re-published on the 50th anniversary of the discovery of the DNA structure. On this Web site, scroll down until you see the section called 'Original Papers'. Click on Watson and Crick's paper. Your teachers may also have printed copies of the article available.

Be prepared to answer these questions during a class discussion unless directed differently by your teacher:

1. Why didn't a triple helix model work to explain DNA structure?

2. What is the novel feature of the Watson - Crick Model?

3. How does the sequence of one side of DNA determine the other side?

4. What is a major significance of this specific structure?

5. Many biologists feel that the discovery of DNA structure is the most significant biological discovery of this century.
   - Why do they feel that the discovery of DNA structure was so significant?
   - Do you agree?
   - Did Watson and Crick deserve the Nobel Prize?

Appendix A: Finding the Structure

Each of the following scientists contributed pieces to the puzzle of the structure of DNA. Read the short descriptions about each in order to answer the following questions.

1. What was Miescher's contribution to our knowledge of DNA?
2. What was Phoebus Levene's contribution to our knowledge of DNA?
3. Why were scientists skeptical about DNA being the stuff of life?
4. What did Oswald Avery's group show?
5. What did Chargoff contribute to solving the puzzle of the structure of DNA?
6. What tool did Franklin provide that enabled Watson and Crick to guess the structure?

Friedrich Miescher: In 1869, this Swiss doctor isolated a new chemical substance. Miescher was interested in cells, which were visible through a new invention, the microscope. As a doctor, Miescher had a ready supply of white blood cells from the pus-filled bandages at the hospital where he worked. Miescher added some simple chemicals to these cells and isolated a white precipitate he called 'nuclein'. Miescher assumed, correctly, that the precipitate was from the large nuclei of the white blood cells. Although not recognized at the time, Miescher had isolated the first crude extract of DNA.

Phoebus Levene: Around 1930 along with some other scientists, Levene found better ways to purify this substance – nuclein. Nuclein was a crude extract and contained a lot of proteins. Once the proteins were removed, the "pure" substance became known as deoxyribonucleic acid because of its sugar structure (ribose-based) and its properties (acidic nature). Levene began deconstructing the DNA components. He found that DNA was essentially a long-chain molecule, made up of four different nucleotides, ribose sugar, and phosphate.

Oswald Avery: Many scientists believed that DNA with its only 4 different components was too simple a molecule to be the template for life. It seemed that proteins with their 20 different amino acid building blocks would have many more combinatorial possibilities. The question became "What is the hereditary molecule – protein or DNA?" In 1944, Avery's group showed that DNA was the transforming principle. When isolated from one strain of bacteria, DNA was able to transform another strain and confer characteristics onto that second strain. DNA was carrying hereditary information, and the stage was set for one of the most exciting periods in DNA science- understanding DNA structure and function.

Erwin Chargoff: Chargoff found there were constant quantities of each of the nucleotides or bases in a given DNA. These would be constant for a species though different for a different species. When looking at amino acids he had never before seen anything where the quantities were in repeatable amounts.

Rosalind Franklin: A methodical X-ray crystallographer who showed that only when you looked at the diffraction patterns from an X-ray could you determine the different possibilities for a model for the structure of DNA. At the time many scientists had been making models but Rosalind knew it was a waste of time until the models were built upon the measurements of a clear diffraction pattern instead of on hypotheticals.

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.blc.arizona.edu/Molecular_Graphics/DNA_Structure/DNA_Tutorial.HTML

http://gslc.genetics.utah.edu/units/basics/builddna/

http://biology.about.com/c/ht/00/07/How_DNA_Model_Candy0962932481.htm

http://www.fa.org/academic/science/dnajewelry.htm

DNA Interactive: http://www.dnai.org/index.htm

The Secret of Photo 51: http://www.pbs.org/wgbh/nova/photo51/
(More information on Rosalind Franklin)

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