FEATURE ARTICLE

Using the Discovery of the Structure of DNA to Illustrate Cultural Aspects of Science

PENG DAI, DAVID RUDGE

Abstract

DNA is a central topic in biology courses because it is crucial to an understanding of modern genetics. Many instructors introduce the topic by means of a sanitized retelling of the history of the discovery of the structure of DNA by James Watson and Francis Crick. Historical research since 1968 has revealed that Rosalind Franklin's contributions were more significant than they are usually depicted. In light of this, we developed a two-class lesson plan that draws attention to Rosalind Franklin's role in the discovery and to the social and cultural aspects of science. The first class provides background information regarding what led scientists to recognize that DNA was the molecule of heredity. Students watch a documentary video that includes interviews with some of the surviving protagonists. Students (working in groups) are then asked to debate Franklin's role to refine their awareness of how social and cultural factors affected both the process of science and how it has been recounted. The second class has students work in groups to build a structural model of DNA through hands-on activities. The essay concludes by drawing attention to how the two-day lesson plan, developed for a college-level biology course, can be adapted for use in other settings.

Key Words: *history of science; biology education; DNA structure; social and cultural aspects of science; gender; Rosalind Franklin.*

○ Introduction

Learning the structure of DNA is considered essential to an understanding of genetics (NRC, 1996; NGSS Lead States, 2013). This being said, students often have difficulty appreciating how the structure of DNA makes many life processes possible, such as the inheritance of genetic information and the synthesis of proteins (Newman et al., 2012). Standards documents are also quite clear that students need to learn more than science content—they need to learn about issues associated with the nature of science (NOS), such as the tentative nature of scientific knowledge (Lederman, 2007).

Learning the structure of DNA is considered essential to an understanding of genetics.

One particularly promising method to help students learn science content *and* issues associated with the NOS is through the history of science (Matthews, 1994; Rudge & Howe, 2004). Teaching science through the use of history demystifies the process of science and provides students with a better understanding of how science relates to other aspects of the world, including social, cultural, and ethical issues (Matthews, 1994). Research suggests the use of history of biology, particularly by means of stories, is an effective way to teach students to appreciate issues associated with the NOS, e.g., the fact that scientific knowledge is socially and culturally embedded (Williams & Rudge, 2015, 2016).

Textbooks often introduce the topic of genetics to students with reference to James Watson and Francis Crick's amazing discovery of the structure of DNA in 1953. Most present this history in a sanitized way, one that plays up the genius of these two white men working in isolation, with minimal reference to the contributions of others whose work made their discovery possible. Historical scholars, in the wake of the publication in 1968 of Watson's autobiographical account, *The Double Helix*, have started to draw particular attention to the neglected role of Rosalind Franklin in these accounts (Gibbons, 2012; Glynn, 2012; Klug, 1968; Maddox, 2002; Sayre, 1975). In light of these considerations, we created a two-day lesson plan that incorporates more of the actual history of how the structure of DNA was first discovered, with emphasis on Rosalind Franklin's contributions. Our specific goals were to engage student interest, and draw their attention to the role of gender as well as other social and cultural influences in this episode. We taught NOS *explicitly* and *reflectively* (c.f. Abd-El Khalick & Lederman, 2000) by making NOS issues a planned instructional activity and by giving students opportunities to reflect on these issues, in this instance by means of arguments and class discussions. Our focus on these issues served as a segway to students developing models of the structure of DNA.

The American Biology Teacher, Vol. 80, No 4, pages. 256–262, ISSN 0002-7685, electronic ISSN 1938-4211. DOI: https://doi.org/10.1525/abt.2018.80.4.256.

○ History Behind the Discovery of the Structure of DNA

Textbooks regularly draw attention to the fact that James Watson and Francis Crick discovered the structure of the DNA molecule in 1953 and were awarded the Nobel Prize together with Maurice Wilkins in 1962. They also draw attention to how the discovery of the structure of DNA paved the way for modern genetics. While Watson and Crick are highly appraised for their work, the role of Rosalind Franklin, who produced the X-ray diffraction image of DNA (Photo 51) that made Watson and Crick's discovery possible, is often neglected (Elkin, 2003; Fausto-Sterling, 2002; Gibbons, 2012; Jungck, 1984; Klug, 1968; Maddox, 2002; Rapoport, 2002; Sayre, 1975).

In the early 1950s, it was already established that DNA (a long molecule of repeating nucleotide bases) was the genetic material. This being said, it was a complete mystery how such a simple molecule (from a chemical standpoint) could contain the information for complex proteins and accurately replicate itself. Watson and Crick (working at Cambridge University) and Wilkins and Franklin (working at Kings College), were among many scientists at the time intrigued by the mystery of figuring out the structure of DNA that gave it these properties. Stylistically, their approach to this problem could not have been more different. Watson and Crick had been hired to do different projects and collaborated together on the structure of DNA in their spare time. Wilkins and Franklin were both hired (in part) to study the structure of DNA, but did not work together, owing in part to a fundamental disagreement regarding whether Franklin had been hired to work as Wilkins assistant or, as she believed, an independent researcher in her own right. Watson and Crick devoted themselves to creating models; Wilkins and Franklin on collecting data, namely X-ray diffraction images of DNA. Franklin focused specifically on refining her technique, because she recognized the information provided by the photographs regarding how the parts of the molecule were arranged would be essential for a resolution of the problem.

In 1951, Watson attended a lecture given by Franklin on her work. She reported discovering that DNA can exist in two forms, A and B. Watson returned to Cambridge with a rather vague recollection of what Franklin had presented, further complicated by the fact that he was still a novice to X-ray crystallography and how to interpret it. One week later, based on his recollections of Franklin's presentation, Watson and Crick proposed their first model for the structure of DNA, which proved to be a complete failure. Ironically enough, Franklin was among the critics who attended this first presentation and pointed out the flaws of their model. This experience solidified her conviction that it was too soon to speculate.

In May 1952, Franklin produced the clearest picture of the B form of DNA (Photo 51). She suspected that both the A and B forms of DNA were helical, but did not want to announce this finding until she had sufficient evidence. As such, she briefly turned her attention back to the A form before announcing her decision to leave Kings College. Her decision stemmed primarily from the ongoing antagonism with Wilkins. But to make sense of why these proved sufficient to lead her to conclude she had to leave Kings, we need to consider other social and cultural factors. At the time Franklin worked in England, the field of science was heavily dominated by men, and indeed women scientists were looked down upon (Crease, 2003; Gibbons, 2012). The personnel committee ultimately accepted her resignation, but on the condition she would finish her analysis of her DNA findings and publish her results. As a result, Wilkins took over her lab and obtained Photo 51, which he shared with Watson without her permission in January 1953. Watson and Crick were at this point in a much better position to correctly interpret the photograph and piece together what the structure of DNA must be. And in February 1953, they announced their discovery of the structure of DNA (Watson, 1968/2012). Their model of its structure so perfectly fit the experimental data that it was almost immediately accepted by the scientific community, including Franklin. But at the time she was unaware of the pivotal role her photograph had played in allowing them to build their model (Ashcroft, 2015; Elkin, 2003; Glynn, 2012; Maddox, 2002).

Watson and Crick's model of the structure of DNA has been called the most important biological discovery of the twentieth century. Only nine years later, in 1962, Watson, Crick, and Wilkins were jointly awarded the Nobel Prize. This happened after Franklin had died in complete ignorance of her contribution and at a time when the Nobel Prize committee rules prohibited the awarding of the prize posthumously. In 1968, Watson published his memoir, *The Double Helix: A Personal Account of the Discovery of the Structure of DNA*, which drew attention for the first time to the crucial role Franklin's research had played in their discovery. Additional historical scholarship since has provided additional evidence. Indeed, some have argued that equal credit should be given to Rosalind Franklin (Gibbons, 2012; Maddox, 2002; Olby, 1974; Rapoport, 2002). The lesson plan below incorporates this historical scholarship. We begin by sharing our learning objectives and how they are assessed before turning to the specific details of the lesson plan, along with recommended modifications for instructors having different needs.

○ Learning Objectives

The lesson plan contains both NOS and content learning objectives. During the first class one of our main objectives, an NOS concept included in the NGSS, is for students to be able to identify that "Science is a human endeavor" (NGSS Lead States, 2013, App. H). More explicit extensions under this category are that men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers; science and engineering are influenced by society, and society is influenced by science and engineering (NGSS Lead States, 2013, App. H, p. 6). Engaging students by sharing a story based on a more accurate representation of the history of research on the structure of DNA, puts them in a position to appreciate the difficulties women scientists experienced in the socio-cultural environment that existed in England during the early 1950s. A follow-up class discussion prompts students to consider the role of gender bias in science with reference to Rosalind Franklin's experiences, and to reflect upon the extent to which gender bias might inhibit the process of science. Arguments about her contribution and the role of gender help students understand the influence of society and culture on science.

The lesson plan also has several other learning objectives with reference to the Next Generation Science Standards. The specific crosscutting concepts, science and engineering practices, and life-sciences core idea met by this lesson plan are listed in Table 1 (NGSS Lead States, 2013, App. E, F, & G). For instance, one of the crosscutting concepts is the relationship between the structure of a molecule and

Table 1. Crosscutting Concepts, Science & Engineering Practices, and Life Sciences Core Idea in the *Next Generation Science Standards* covered by this class.

Crosscutting Concepts	Part of Lesson
Patterns: Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.	After watching the video and summarizing the main features of DNA structure, students identify patterns, including how it is composed of repeating nucleotide base pairs.
Cause and effect: Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.	During the students' presentation, they attempt to explain the underlying causes of the DNA structural patterns and interpret the functions associated to DNA replication process.
Structure and function: The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.	During the students' presentation, they interpret functions associated with the process of DNA replication in terms of underlying structural patterns.
Science & Engineering Practices	**Part of Lesson**
Developing and using models	Students are asked to design and construct DNA models and to describe the structure of DNA.
Engaging in argument from evidence	Students are required to create arguments that include both evidence for their position and justification of their response.
Obtaining, evaluating, and communicating information	Students working in groups share and evaluate arguments with their peers.
Life Sciences Core Idea	**Part of Lesson**
Inheritance of traits: DNA carries instructions for forming species' characteristics. Each cell in an organism has the same genetic content, but genes expressed by cells can differ.	By explaining the process of DNA replication based on the DNA structure, students demonstrate their understanding that all the cells in an organism have the same genetic content.

its function. During the second day of the class, students are asked to explain the semi-conservative mode of DNA replication with reference to their understanding of DNA structure and, in particular, the fact that it exists as a double helix. Each strand of the original molecule serves as a template for a new complementary strand, thus ensuring faithful replication of the DNA molecule.

○ Assessment

We use class discussions to assess students' understanding of the issue associated with NOS, and presentations of DNA structural models to assess their learning of DNA content. During the first day, students are asked to answer and discuss the open-ended questions on Handouts 1 and 2 (Appendix), through which the instructor can identify students' understanding of the social and cultural aspect of NOS. For the second day of the lesson, the instructor can evaluate students' presentation on their DNA model using the presentation rubric (Handout 3, Appendix), which provides the instructor with information on the students' understanding of DNA content covered in this lesson.

○ DNA Structure Lesson Plan

We created our two-day lesson for use in a college introductory biology course for non-majors, but (as indicated below) we have several suggestions for how to modify it for use in high school and other settings.

○ Materials

- One computer to play the PowerPoint and the NOVA video, "DNA—Secret of Photo 51"
- Handout 1 with discussion questions for Day 1 (Appendix)
- Handout 2 with argumentation table for Day 1 (Appendix)
- Supplies and rubric for making DNA models and giving presentations (Handout 3, Appendix)

○ Preparation

We created our lesson plan based on the history of the discovery of the structure of DNA specifically to illustrate the role of gender and other social and cultural factors in science. The class is introduced to this history by means of a 52-minute video, "DNA—Secret of Photo 51," produced for PBS (Public Broadcasting Service) and made available online by WGBH. It is currently available on both the NOVA website and YouTube. The video reviews the history of how the structure of DNA was discovered, discusses the semi-conservative nature of DNA replication, and includes extensive interviews with surviving major participants. We have found that the video is a particularly effective way to engage students and deepen their understanding of the history behind the discovery.

○ Procedure: Day 1

During the first class the instructor presents background information about DNA by means of a PowerPoint. The presentation introduces DNA as a long chain (polymer) composed of repeating units (monomers) called nucleotides. They also learn that nucleotides are composed of three components—(1) a nucleotide base (adenine, thymine, guanine, cytosine), (2) a sugar (2′-deoxyribose), and (3) a phosphate group—and how new nucleotides are added on to the growing polymer. We also introduce Chargaff's rule (a general pattern found among DNA molecules in nature), which states: for any given molecule of DNA, the amount of adenine is always equal to the amount of thymine, and the amount of cytosine is always equal to the amount of guanine. After this we ask students to think through and share answers to the first question on Handout 1 (Appendix). We have found this assists us in assessing students' knowledge before we continue to the remainder of the lesson. We then briefly introduce James Watson, Francis Crick, Maurice Wilkins, and Rosalind Franklin. We emphasize that they are among many scientists during the 1950s who were interested in unraveling the mystery surrounding the structure of DNA. At this point, our presentation using the PowerPoint has made students aware of all of the relevant information scientists had at the time the protagonists began their research. It is presented by means of the story specifically to intrigue students into wondering how scientists were ultimately able to discover the structure of DNA.

After this background information has been shared, students are asked to read over five additional open-ended questions on Handout 1 for later class discussion. Students watch a brief video, "DNA—Secret of Photo 51," which narrates the history of the discovery of DNA structure. Students are then are asked to work in groups and complete the remaining questions on Handout 1 regarding how the process of science, as illustrated in the film, is affected by culture and society. Students are then required to share their thoughts and have a class discussion on each question. For example, students discuss how Watson and Crick recognized that DNA must be a double helix. In our own class, most students agree that Rosalind Franklin played a critical role in the process of discovering the structure of DNA. They also acknowledge how the social and cultural environment in England led to the gender bias and negatively influenced female scientists working in that time period.

Students, working individually, are next asked to explore the episode from an ethical perspective by filling out Handout 2 (Appendix). Students are asked to consider both *would* and *should* Franklin have received the Nobel Prize with Watson, Crick, and Wilkins if she had lived? Students are asked to create arguments for their position that both includes evidence for their position and explains their response. In this way, the process of having students reflect on these questions improves students' critical thinking skills and helps them understand in concrete ways how society and culture influence science. Students working in groups then share and evaluate arguments with their peers. In our class, we've found students generally agree that, had she lived, Franklin *should* have received the Nobel Prize. For instance, one of our students responded, "Rosalind Franklin should be awarded the Nobel Prize with Watson and Crick because she provided the crucial information to the last step of creating the structure of DNA." However, with regard to the other question, which asks students to speculate on what *would* have happened if Franklin was alive at the time that the Nobel Prize was awarded for the discovery, students often disagree. For example, one of our students responded, "Rosalind Franklin would have received the Nobel Prize because she would have stood up for herself and defended her research," whereas another student responded, "She would not have received it because women were still persecuted by a dominant male social environment." The first day of the lesson concludes with students discussing an open-ended question: If you were either Watson or Crick, what would you have done? The discussion will not only serve as an opportunity for students' further reflection on NOS as illustrated by the Franklin story, but will also help students to appreciate these issues are part of contemporary science as well.

○ Procedure: Day 2

The second day begins by having students summarize what they have learned in terms of the content, the main features of DNA, from the last class. We've found that our use of a story based upon Rosalind Franklin's experiences leads to greater student recall and understanding of both the structure of DNA and the details of the discovery. Students recognize that DNA is a polymer composed of nucleotides and takes the form of a double-stranded helix. They know that adenine always pairs with thymine, and guanine always pairs with cytosine in DNA. The two DNA strands run in opposite directions. Students recognize that Watson and Crick's discovery of the actual structure of DNA was made possible by crucial evidence furnished by Rosalind Franklin, and further, how her important role in the discovery was and has been diminished in the retelling of the story. The instructor then discusses the process of DNA replication, building off of the video's previous discussion of the semi-conservative mode by which replication takes place. Our goal at this point is to connect student understanding of the semi-conservative nature of replication with the structural properties of the DNA molecule that allow this process to take place.

Students are next asked to work in groups and design a structural model of DNA that incorporates the main features they just reviewed. The instructor supplies students with both a rubric (Handout 3, Appendix) and materials that allow them to create a physical model of DNA. In our introductory biology course, we provide a diversity of materials to encourage student creativity: such as two sizes of paper clips, colored pipe cleaners, styrofoam sheeting, colored papers, marshmallows, spaghetti, gummy bear, etc. The rubric contains guiding requirements designed to focus students' attention on the main features of DNA molecule. Before they start to make the DNA structural model, students are required to draw their blueprints of it on the white boards provided for each group. In particular, they need to make decisions on what materials they will use to represent each part of the molecule. As students work through their blueprints and models, the instructor walks around providing suggestions and answering questions. This hands-on activity of making DNA models can contribute to students' understanding of the abstract concepts of the structure of DNA and how this structure is related to the functions of DNA, despite the fact that the molecule is microscopic. The class concludes with presentations of students' models. These presentations serve as an opportunity to assess students' understanding of science content.

○ Activity Modifications

The following are recommended modifications of the lesson plan for use by instructors who might need to customize depending upon their particular needs:

- *Alternative ways to use the video*. Another way to use the video would be in combination with Handout 1, i.e., pausing the film at various points to give students opportunities to think and discuss the questions on Handout 1 while viewing the video. Depending upon the objectives of the instructor, showing parts of the video, rather than the whole video might be an option.
- *Alternative ways to teach the lesson without the video*. Instructors can alternatively create a PowerPoint to present this story and illustrate different personalities of the scientists and many crucial features of the scientific process (Emani, 2010). Students could also read either Watson and Crick's original paper (2003 [1953]) or a brief summary of the paper written in a way that is grade-level appropriate.
- *Alternative ways to use the in-class DNA modeling activity*. The activity of developing a DNA structural model could be assigned as team homework to be completed outside of class using the rubric and materials students find at home.
- *Alternative ways to use the lesson to teach the NOS*. The lesson plan could be elaborated to focus on an additional NOS objective, "Imagination and creativity in scientific investigations." Creativity occurs throughout the scientific process, from coming up with new ideas and research questions to collecting, analyzing, and interpreting data (Lederman et al., 2002). During the first class, instructors could add an additional discussion question to Handout 1: "Do you think Watson and Crick used their imagination and creativity in their investigations? If yes, please explain why with examples. If not, please explain why not." The video about Watson and Crick figuring out the specific pattern about the bases A, T, C, and G bonded, constructing the DNA model, and discovering the structure of DNA provides an example of how scientists use imagination and creativity in their investigations. If time permits, instructors could additionally use a formal assessment created by the Lederman group named VNOS (Views on the Nature of Science), which includes a specific question about social and cultural influences on science (Lederman et al., 2002). The VNOS questionnaire could be used before and after the history-based class to assess change in student understanding of NOS concepts.

○ Conclusion

Our experiences using this lesson plan in class, particularly students' responses to the questions provided in Handouts 1 and 2 suggest students find issues associated with NOS, especially the social and cultural influences on science, to be particularly engaging. The fact that students were able to correctly build DNA models and make successful presentations suggests that the historical lesson plan, far from distracting students, actually enhances student understanding of the structure of DNA. Asking students to present their views by means of arguments is one way to help them improve critical-thinking skills, as when they respond to questions and challenges from other students. We find this historical lesson plan helps students better understand not only scientific content, but also the process of science. Therefore, we recommend instructors use this lesson plan for improving students' learning of the structure of DNA as well as their understanding of social and cultural aspects of science often left out in the science classroom.

○ Resources

The NOVA video "DNA—Secret of Photo 51" is available for free online at https://www.youtube.com/watch?v=0tmNf6ec2kU

The argumentation worksheet was revised by authors based on V. Sampson, *Argument-driven inquiry in biology: Lab investigations for grades 9–12* (Arlington, VA: NSTA Press, 2014).

References

Abd-El Khalick, F., & Lederman, N. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching*, *37*(10), 1057–1095.

Ashcroft, F. (2015). Rosalind Franklin and Photograph 51. *The Lancet*, *386*(10002), 1439–1440.

Crease, R. P. (2003). The Rosalind Franklin question. *Physics World*, *16*(3), 17.

Elkin, L. O. (2003). Rosalind Franklin and the double helix. *Physics Today*, *56*(3), 42–48.

Emani, C. (2010). Using the "DNA story" to inculcate a scientific thought process in the classroom. *American biology Teacher*, *72*(7), 410–413.

Fausto-Sterling, A. (2002). Gender and Science in the DNA Story. *Science*, *298*(5596), 1177–1178.

Gibbons, M. (2012). Reassessing discovery: Rosalind Franklin, scientific visualization, and the structure of DNA*. *Philosophy of Science*, *79*(1), 63–80.

Glynn, J. (2012). *My Sister Rosalind Franklin*. Oxford: Oxford University Press.

Jungck, J. R. (1984). The DNA helix, featured scientist: Rosalind Franklin: "Bold Experimentalist." *American Biology Teacher*, *46*(8), 430–472.

Klug, A. (1968). Rosalind Franklin and the discovery of DNA. *Nature*, *219*, 808–844.

Lederman, N. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. Lederman (Eds.), *Handbook of Research in Science Education* (pp. 831–880). Mahwah, NJ: Erlbaum.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*(6), 497–521.

Maddox, B. (2002). *Rosalind Franklin: The dark lady of DNA (1st ed.)*. New York: HarperCollins.

Matthews, M. (1994). *Science Teaching: The Role of History and Philosophy of Science*. New York: Routledge.

National Research Council (NRC). (1996). *National science education standards*. Washington, DC: National Academies Press.

NGSS Lead States. (2013). Topical arrangement of the *Next Generation Science Standards*. Retrieved from http://www.nextgenscience.org/search-standards

Newman, D. L., Catavero, C. M., & Wright, L. K. (2012). Students fail to transfer knowledge of chromosome structure to topics pertaining to cell division. *CBE-Life Sciences Education*, *11*(4), 425–436.

Olby, R. C. (1974). *The path to the double helix: The discovery of DNA*. N. Chelmsford, MA: Courier Corporation.

Rapoport, S. (2002). Rosalind Franklin: Unsung Hero of the DNA Revolution. *The History Teacher*, *36*(1), 116–127.

Rudge, D. W. & Howe, E. M. (2004) Incorporating history of science in the classroom. *The Science Teacher*, *71*(9), 52–57.

Sayre, A. (1975). *Rosalind Franklin and DNA* (1st ed.). New York: WW Norton & Company.

Watson, J. D. (2012). *The double helix: A personal account of the discovery of the structure of DNA*. Oxford: Atheneum. (Original work published 1968.)

Watson, J. D., & Crick, F. H. (2003). A structure for deoxyribose nucleic acid, 1953. *Nature*, *421*(6921), 397.

Williams C. T., & Rudge, D. W. (2015). Mendel and the nature of science. *American Biology Teacher*, 77(7), 492–499.

Williams C. T., & Rudge, D. W. (2016). Emphasizing the history of genetics in an explicit and reflective approach to the teaching of nature of science: A pilot study. *Science & Education*, *25*(3–4), 407–427.

PENG DAI (peng.dai@wmich.edu) is a Research Doctoral Associate at the Mallinson Institute for Science Education at Western Michigan University, 1903 W. Michigan Ave., Kalamazoo, MI 49008-5444.
DAVID RUDGE (david.rudge@wmich.edu) is an Associate Professor of the Department of Biological Sciences and the Mallinson Institute for Science Education at Western Michigan University.

Appendix

Handout One

Video Worksheet

We will watch the NOVA video named "DNA-Secret of Photo 51." Please read over all of the questions and answer Question 1 in preparation for our later discussion.
1. James Watson, Francis Crick, Maurice Wilkins, and Rosalind Franklin are the scientists associated with the discovery of DNA structure. Have you ever heard of them? And, if so, from where? What do you know about them?
2. What was the social and cultural environment in England at that time that negatively influenced female scientists?
3. Rosalind Franklin, as depicted in the film, seems to have a difficult time interacting with the other scientists. To what extent would you attribute this to her individual personality, and to what extent does it reflect how women were (are) treated by male scientists? Explain your answer.
4. Describe the contribution of the following scientists in the discovery of the structure of DNA: James Watson, Francis Crick, Maurice Wilkins, and Rosalind Franklin.
5. How did Watson and Crick recognize that DNA must be a double helix? Were any values or ethics violated by these researchers? Explain your answer.
6. In what ways does the social (or institutional) structure of science, as revealed in this film, promote or inhibit scientific activity? Explain your answer.

Handout Two

Leading Question: If Rosalind Franklin had lived, would she/should she have received the Nobel Prize with Watson, Crick, and Wilkins? Work in groups, discuss with your peers, and fill in the argumentation worksheet individually, and defend your answers.

Argumentation Worksheet

Constructing and Argument		
The Leading Question	**Would** Franklin have received the Nobel Prize with Watson, Crick, and Wilkins if she had lived?	**Should** Franklin have received the Nobel Prize with Watson, Crick, and Wilkins if she had lived?
Our Claim		
Our Evidence		
Our Justification of the Evidence		

Handout Three

Three-Dimensional DNA Model and Presentation Rubric

Instructions:

- Design and use the available materials to build a three-dimensional DNA model based on what we learned about DNA structure in the last class.
- Pick supplies (two sizes of paper clips, colored pipe cleaners, Styrofoam sheeting, colored papers, marshmallow, spaghetti, gummy bear, etc.) to represent the main components of DNA including: sugar, phosphate, and bases (adenine, guanine, cytosine, or thymine).
- Use this sequence for one half of the DNA molecule: 3′ CATAGTGCCA 5′
- Give a presentation, in groups of two or three, explaining the structure of DNA.

Checkout Questions:

Before you start to build the DNA model, use the white board to draw a blueprint that illustrates the structure of DNA. Discuss with your partners about how you are going to build the model and what materials you will use to represent each main molecule.

Grading Rubric:

1. The model contains three main building blocks (sugar, phosphate, base), and each molecule is represented by different materials. The four bases (A, T, G, and C) should be represented by four different colors.

   ____________/1

2. The model should match the sequence given above.

   ____________/1

3. The model should follow Chargaff's rule: adenine bonded to thymine and cytosine bonded to guanine.

   ____________/1

4. The model consists of two strands and is double-helix shaped.

   ____________/1

5. The two strands are anti-parallel directions, and the 3′ and 5′ ends are properly represented.

   ____________/1

6. The model is accurately labeled or a key is attached.

   ____________/1

7. The model is three-dimensional and can be physically twisted.

   ____________/1

8. The model is neat and creatively constructed.

   ____________/1

9. The presentation is clear and well organized.

   ____________/1

10. Everyone in the group contributes to the presentation.

    ____________/1

    Total Points___________/10