

X Marks the Spot:
The Rosalind Franklin Story

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Senior Division

Group Documentary

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Before this project, all we knew of Rosalind Franklin was a vague grasp of her contributions to understanding DNA and status as a feminist icon. By the end, we discovered a revolutionary chemist whose impacts on humanity ranged from life-saving gas masks in World War II to precision medicine to more efficient vaccinations, all of which save lives.

Our research began with the two biographies of Franklin: Anne Sayre's *Rosalind Franklin and DNA* and Brenda Maddox's *The Dark Lady of DNA*. Then, we looked online for more specific information regarding her work on DNA and viruses. We found several comprehensive databases. As Riley tackled published information on Franklin, A.J. scheduled interviews. Brief correspondence with Jenifer Glynn, Rosalind's younger sister, revealed Franklin's personal life. A reason we chose this topic was the opportunity A.J. had to visit the UK, where he examined primary sources, including Franklin's original lab notes. Dr. Patricia Fara aided in examining primary sources at Churchill College, Cambridge and invited A.J. for tea at the Fellows' Room. She introduced an opinion on Franklin gaining popularity among historians—that Rosalind would not have endorsed her modern mythologization as a casualty of prejudice. We ultimately chose this position in our film. In Britain, A.J. interviewed Dr. Laura Holland of Oxford University's Rosalind Franklin Institute—considered the pinnacle of Franklin's legacy by her sister Jenifer Glynn—and Rosalind's brother, Colin Franklin. Most of the footage in the documentary are original shots. After the state competition, we expanded our project through a phone interview with Dr. Donald Caspar—a colleague of Franklin—and Director of the National Institutes of Health Dr. Francis Collins.

We chose a documentary because it allows for quick transitions between scenes, reflective of Franklin's restless life and her many scientific triumphs. First developing her

crystallography skills in carbon research, she later applied them to DNA and viruses. She demonstrated that seemingly insignificant work could prove to be a great triumph when her research on coal saved lives during the Second World War. Her triumph of a remarkable 42 scientific papers by the age of 37 contrasts with the tragedy of further contributions she could have made. However, this tragedy never overshadowed her triumphs. Not only did she discover amazing properties of the natural world, but she also inspired people to look more carefully at the data, to imagine something outside of the box, and challenge the status quo.

While Watson and Crick's famous discovery of the double helix led to medical improvements that continue to save countless lives, it relied on Rosalind Franklin's experimental data. Franklin was a tragic hero whose strength and uncompromising dedication was also a hindrance in Britain's segregated scientific culture. Her early death was the greatest tragedy, but Rosalind Franklin's work on coal, DNA, and viruses remain triumphs that far outlive her. The legacy Franklin left behind was more than discoveries; it has grown to live in every person who shares her goal to realize "the improvement of mankind."

Annotated Bibliography

Primary Sources

Articles

Franklin, Rosalind, and Raymond Gosling. *Rough draft of "A Note on Molecular Configuration in Sodium Thymonucleate."* 17 Mar 1953.

This early draft of the article that appeared with Watson and Crick's announcement in *Nature*, April 25, 1953, shows that Franklin was preparing to publish what she knew about the B form of DNA, in addition to the work she had already written on the A form. The draft is dated March 17, one day before the news of the Watson-Crick model reached her. Inserted by hand into the original text is the sentence, "Thus our general ideas are consistent with the model proposed by Crick in Watson." With hindsight, we can infer she wrote this after Watson and Crick invited her to view their model which—little did she know—was based on her experiments.

Klug, Aaron, and Rosalind Franklin. Order-Disorder Transitions in Structures Containing Helical Molecules. *Discussions of the Faraday Society* 25. 1958.

This article, published after her passing, marks a final visit to DNA from Franklin. Here, she examines with Klug the prospect of how single-stranded DNA molecules bind into double-stranded ones as well as how DNA gets organized into chromosomes. Klug and Franklin accurately observed that it came down to structure in both cases, noting how grooves in the bases allowed for the RNA Primer (as we now know it) to attach to the DNA and pave the way for DNA Polymerase. Moreover, their assertions that the chromosomal formation had to be manipulated by proteins was—while less precise—correct.

Pauling, L and R B Corey. *A Proposed Structure for The Nucleic Acids*. *Proceedings of the National Academy of Sciences of the United States of America* vol. 39, 2 (1953): 84-97. scarc.library.oregonstate.edu/coll/pauling/dna/papers/1953p.9.html.

This is the article that Pauling published which proposed the triple helix structure. While Franklin looked it over and found several errors in his reasoning, Pauling was extremely close to the discovery. We accessed this primary source online so we could learn about Pauling's theory, and we use it in our documentary to further expand on the timeline.

Watson, James D., and Francis Crick. *Molecular Structure of Nucleic Acids: A Structure for Deoxyribose Nucleic Acid*. Nature 171. 25 April 1953.

This is Watson and Crick's concise, understated original explication of their double helical model of DNA and its key feature, the complementary pairing of the purine and pyrimidine bases on the inside of the molecule. The schematic drawing of the double helix was provided by Crick's wife, Odile, a trained artist. Although it has since become canonical, one of the best-known articles in the scientific literature, it was not often cited during the early years after its publication. Its significance was acknowledged fully by biochemists and other scientists, and it became a standard reference, only after the mechanism by which DNA directed the synthesis of proteins, the building blocks of life, was elucidated in the late 1950s. Although Watson and Crick acknowledged Rosalind Franklin's X-ray diffraction studies of DNA, they did not fully disclose the extent to which their theory rested on her experimental evidence, an intellectual and moral debt they struggled to discharge over the course of several decades.

Interviews

Casper, Donald. Personal Interview. 24 Apr. 2019.

Dr. Donald Casper was one of Franklin's colleagues. While this was a phone interview and not face-to-face, it was still very interesting and informational. Dr. Casper told us about what Franklin was like in the workplace, as well as a very interesting story about their first meeting. He also explained that Franklin was still faced with extreme prejudice and sexism, despite her recognition as a distinguished scientist.

Franklin, Colin. Personal Interview. 19 Dec. 2018.

Our interview with 95 year-old Colin Franklin, Rosalind's brother and close friend, enlightened us to details of Rosalind's personal life and what she was like outside of work. We heard many unpublished stories about Rosalind's love for photography and science, her musical ineptitude, and one about her suddenly entering a hat shop and requesting 250 hat stands for her polio model. We feel incredibly honored to have conducted this interview and to be able to use it to complete our knowledge. We refer to this interview when we discuss Rosalind's personal life.

Glynn, Jenifer. Personal Interview. 17 Sep 2018.

Jenifer Glynn was Rosalind's younger sister. We interviewed her so we could understand Franklin better. By understanding who someone is, we can tell why she did something, which plays into her impact. Ms. Glynn told us that Franklin saw herself first as a scientist, not a woman. We use this in the documentary to highlight that Franklin was extraordinarily dedicated to her beliefs. We are also able to understand that Franklin wanted to make humanity better through science, which was one of her greatest triumphs.

Letters

Coulson, C.A. Received by Rosalind Franklin, Churchill Archives Centre, 11 June 1948, Cambridge UK.

C.A. Coulson was a theoretical chemist and physicist who developed a molecular orbital theory and the concept of partial valency. Franklin had worked with him during her time at BCURA and asked him to review her first submission to *Nature*, the eminent British scientific journal. The "letter," titled "On the Influence of the Bonding Electrons on the Scattering of X-Rays by Carbon," was published in January 1950. It was Coulson who suggested that Franklin look for a position at King's College if she wanted to work in the new field of biophysics.

Franklin, Rosalind. Received by Ellis Franklin, Held by Jenifer Glynn, 1939, Cambridge, UK.

This letter, written by Rosalind to her father Ellis Franklin, was a dispute between the two regarding the family's charitable tradition. Her father pressured her to carry it on, but Rosalind replied that she would be of little use in anything but science. When he accused her of making science her religion, she responded with this letter, writing, "In my view, all that is necessary for faith is the belief that by doing our best we shall succeed in our aims: the improvement of mankind." We used this quote as our epigraph as it defines Franklin's motivations.

Franklin, Rosalind. Received by J.T. Randall, Churchill Archives Centre, 24 Nov 1950, Cambridge, UK.

After arranging to return to England for a Turner and Newall fellowship at King's College, London, Franklin had to think about the design of the x-ray apparatus she would use there and arrange to have it manufactured. In this letter, she told Randall of her plan, and of possible complications with the equipment.

Klug, Aaron. Received by Philip Siekevitz, Churchill Archives Centre, 14 Apr 1976, Cambridge UK.

Anne Sayre's 1975 biography made Franklin's many accomplishments much more widely known, and she was posthumously honored as a pioneering feminist as well as an excellent scientist. The president of the New York Academy of Sciences asked Aaron Klug to recommend Franklin for a special "woman of science" award. In this letter, Klug responded, and recommended that Franklin be honored for her crucial contributions, not as a "woman of science." She was never an active feminist—he noted—and might have found it distasteful to be celebrated as one.

Randall, J. T., and King's College London. Received by Rosalind Franklin, Churchill Archives Centre, 4 Dec 1950, Cambridge, UK.

In this letter, J. T. Randall told Franklin that he wished to change the focus of the work she planned to do at King's College. Instead of studying proteins in solution, she would look at DNA fibers. He stated that "as far as the experimental X-ray effort is concerned, there will be at the moment only yourself and Gosling . . ." thereby setting the stage for conflicts between Franklin and Maurice Wilkins.

Franklin, Rosalind. Received by John Desmond Bernal, Churchill Archives Centre, 19 June 1952, Cambridge, UK.

Unhappy at King's College in early 1952, Franklin asked J. D. Bernal if she might transfer to his biophysics lab at Birkbeck. He agreed, but as this letter shows, it took a long time to make the arrangements; Franklin was unable to make the move until March 1953. This letter helped determine the time Franklin made the arrangements for the transfer to Birkbeck. Before it, we were limited to the vague periods described by secondary sources of 'late 1952' or '1953.'

Randall, J.T. Received by Rosalind Franklin, Churchill Archives Centre, 17 Apr. 1953, Cambridge, UK.

After Franklin's departure from King's College, Randall wrote this letter demanding that she cease working on DNA problems as soon as possible, and also cease advising her former assistant, graduate student Raymond Gosling, about his graduate work. She finished writing up her DNA work during 1953 but continued to mentor Gosling.

Siekevitz, Philip. Received by Aaron Klug, Churchill Archives Centre, 26 Mar 1976, Cambridge, UK.

Anne Sayre's 1975 biography made Franklin's many accomplishments much more widely known, and she was posthumously honored as a pioneering feminist as well as an excellent scientist. In this letter, the president of the New York Academy of Sciences asked Aaron Klug to recommend Franklin for a special award.

Lab Notes

Franklin, Rosalind. College notebook on crystal analysis. Churchill Archives Centre, 1940.

In her undergraduate notes on nucleoproteins, Franklin observed, "Genes packed in particular positions along chromosomes—geometrical basis for inheritance?"

Franklin, Rosalind. College notebook on x-ray crystallography. Churchill Archives Centre, 1940, Cambridge UK.

Franklin's detailed notes from an undergraduate course in crystallography cover some of the basic concepts, such as Laue equations, and equipment such as the Weissenberg camera.

Franklin, Rosalind. Lab notes on DNA x-ray diffraction experiments. Churchill Archives Centre, Sep 1951 - Mar 1952, Cambridge UK.

In this lab notebook, Franklin recorded her initial x-ray diffraction work on DNA, including her preparation techniques and ongoing problems with equipment. By early 1952 her notes differentiate between "wet" and "crystalline" forms. Franklin's discovery that there are two forms of DNA is perhaps the most crucial step toward the ultimate discovery of its structure.

Franklin, Rosalind. Lab notes. Churchill Archives Centre, Mar - Oct 1952, Cambridge UK.

In this lab notebook, Franklin recorded the progress of her x-ray diffraction studies of the A form of DNA, including exposure times and adjustments to specimens and equipment. Among the notes are those she took on her famous Photo 51 which—to our surprise—showed an accurate measurement of the distance between nitrogenous bases in DNA. She also included her reasoning on the results of the cylindrical Patterson analysis, which did not seem to show a helical structure.

Franklin, Lab. Lab notes on chains in DNA structure. Churchill Archives Centre, 10 Dec 1952, Cambridge UK.

This lab note made in late 1952 shows Franklin's thinking about the number of ribose chains that DNA might have, based on her research so far. Aaron Klug, her scientific executor, added a penciled note in the upper right corner.

Franklin, Rosalind. Lab notes on possible DNA structure. Churchill Archives Centre, Jan - Jul 1953, Cambridge UK.

Early in 1953, Franklin was evaluating her x-ray diffraction data and working out possible structural configurations for DNA, especially the B form. After Watson and Crick presented their DNA model, Franklin looked at how it fit with her findings on the A form, recording her reasoning in this notebook. Our investigations on the originals with Dr. Fara generated a curious observation: the handwriting in this notebook appears different than the handwriting in the collection's other notebooks. Knowing that Gosling typically took the actual photos and that the other notebooks are about the specific conditions in which each photo was taken, we hypothesize that the other notebooks—attributed to Franklin—may have actually belonged to Gosling.

Franklin, Rosalind. Notes on Pauling and Corey's "Proposed Structure for Nucleic Acids." Churchill Archives Centre, 1953, Cambridge UK.

In January 1953, Linus Pauling proposed a three-helix structure for DNA. However, as Dr. Fara so eloquently put it in our interview, Franklin "absolutely rubbishes it." She found several errors in Pauling's reasoning, based on her own research, which are jotted down here. She later wrote to Pauling, explaining why his model was wrong, though she did not succeed in changing his mind.

Randall, J.T.. Specific Optical Rotation of Nucleic Acid. Churchill Archives Centre, 28 Nov 1951, Cambridge UK.

As Franklin was wrestling with the structural implications of her x-ray data on DNA, Randall contributed this note on a possibly useful method for looking at the problem. The idea of layering sheets of DNA rather than individual fibers proposed here was embraced by Franklin. The results were a primary cause of her ultimate conclusion that the B form of DNA must be double helical.

Books

Glynn, Jenifer. "Rosalind Franklin 1920-1958." In *Cambridge Women: Twelve Portraits*. Edited by Blacker and Shils. New York: Cambridge University Press, 1996.

This essay on Rosalind, written by her sister Jennifer, provided a marked contrast to Watson's caricature of a miserable and boring "Rosy." While she is keen to object to Watson, she is equally content to oppose her mythos as a victim of male prejudice. She begins by pointing out that Rosalind would not have liked being in a book containing stories of women exclusively. This was a large reason we chose to focus the documentary's tragedy on Franklin's early death and lack of resources than the usual misappropriation of credit.

Watson, James D. *The Double Helix: A Personal Account of the Discovery of the Structure of DNA*. Atheneum, 1968.

If ever there was a book that should be prefaced with context, it was *The Double Helix*. It is a fine literary read, but a deplorable historical source. In fact, Crick and Wilkins objected so strongly that—in a highly unprecedented move—Harvard University Press withdrew its offer to publish, though another press was eventually found. The factual inaccuracies alone took Francis Crick 15 pages to rebuke in an essay. He uses the character of "Rosy" (not-so-secretly referring to Rosalind) as the belligerent and villainous woman from whom he and Crick needed to rescue DNA. Its contributions were minimal in our final product, but of overwhelming influence in our understanding of how Watson approached Franklin and the race at large.

Videos

Clinton, Bill, and Tony Blair. *Human Genome Announcement at the White House (2000)*. NHGRI, 29 Aug. 2012. www.youtube.com/watch?v=slRyGLmt3qc.

This is the video of President Bill Clinton and Prime Minister Tony Blair announcing the completion of the human genome project. Francis Collins, the project's head researcher, famously said, "Today we are learning the language with which God created life." We used this video at the beginning of our project to emphasize Franklin's impact on the whole world. Even though her DNA research occupied a relatively brief period in her successful career working on a variety of topics, this event captures the immense importance of that work.

Reports

Franklin, Rosalind. *Annual Report for Turner-Newall Fellowship, 1 January 1953 - 1 January 1954*. Jan. 1954.

This report on the final year of her Turner-Newall Fellowship detailed the last of Franklin's work on DNA at King's College and the start of her work on viruses at Birkbeck College, including her research plan and the equipment she would use. Of particular relevance, she included interpretations of many of her x-ray diffraction photos. It was these same interpretations that Watson and Crick would dubiously obtain (through Maurice Wilkins—who disliked Franklin—and their thesis advisor Max Perutz) and which would guide them towards the accurate measurements and chemical balances of the molecule's structure.

Images

Franklin, Rosalind, and Raymond Gosling. *Photo 51*. 2 May 1952, King's College, London.

When developed, this photograph would reveal the structure of DNA and the key to understanding how the blueprint for all life on earth is passed down from generation to generation. It took over one hundred hours to develop, and Franklin had not finished her interpretations by the time she left King's just under a year later. Our documentary was titled "X Marks the Spot" because of this photo: the X shape in the middle is the diffraction signature of a helix and the measurements were also calculable from the image. It alone could provide Watson and Crick with everything they needed to know about DNA's structure except the base pairing. It was the proof of a double helix.

The Rosalind Franklin Papers. Churchill Archives Centre, Cambridge, UK.

This archive was the source of every image of Rosalind used in the documentary. It also contained photos of her Birkbeck lab taken shortly after her passing.

Archives and Special Collection. King's College London, London, UK.

The source for images of King's College: the exterior, Randall's lab, and more.

The Nobel Prize. NobelPrize.org. Digital.

A source for images of various characters in the story, including Wilkins, Watson, Crick, as well as footage of both the 1962 and 1982 Nobel Prize ceremonies.

Ava Helen and Linus Pauling Papers. Oregon State University. Digital.

Contained all images of Linus Pauling and miscellaneous historical images relating to the DNA race.

Secondary Sources

Articles

Klug, Aaron. *Rosalind Franklin and the Discovery of the Structure of DNA*. *Nature*, 219 (August 1968): 808-810, 833-844.

In this article, Aaron Klug discusses Franklin's contribution to the discovery of the structure of DNA in the light of accounts given by James Watson in his book *The Double Helix* and by Dr. Hamilton in another article in *Nature*.

Klug, Aaron. *Rosalind Franklin and the Double Helix*. *Nature* 248 (April 1974): 78.

Klug explains that a draft manuscript shows how near Rosalind Franklin came to finding the correct structure of DNA. Indeed, she had all ingredients to proving the structure except for how the bases paired. It is no wonder Francis Crick himself would admit that Franklin was likely only three weeks from discovering the structure by herself.

Books

Judson, Horace Freeland. *The Eighth Day of Creation: Makers of the Revolution in Biology*. Simon and Schuster, 1979.

This is a richly detailed account of how molecular biologists came to understand the fundamental processes of life—in short, how they explained heredity. It discusses in great clarity and accuracy the precise roles of Franklin, Wilkins, Watson, and Crick, noting that the latter two were merely synthesizers of the data the former had collected. The “true experimentalist,” Judson wrote, was Franklin.

Maddox, Brenda. *Rosalind Franklin: The Dark Lady of DNA*. HarperCollins Publishers, 2002.

This biography written about Rosalind Franklin is extraordinary and goes into incredible detail about every stage of Franklin's work. It also cites several primary sources, such as letters written by or to Rosalind. The comprehensive detail found in this book made it our most important secondary source. We used it to learn about Rosalind's college life, DNA work, and virology work.

Olby, Robert. *The Path to the Double Helix: The Discovery of DNA*. Dover Publications, Inc., 1974.

Prof. Robert Olby reaches conclusions in his book which are to the opposite of ours, especially his remark that Franklin was anti-helical in her speculation of DNA's structure. It is rightfully regarded as the most comprehensive scientific history of the molecule of DNA through the 1962 Nobel Prize. Of relevance to us was why Olby concluded that Franklin was 'anti-helical' and what x-ray diffraction of DNA looked like from its beginnings through the sixties. The detail of Franklin's photos remained unrivaled for over 20 years after Photo 51. This was also a good source about Oswald Avery's 1943 experiments.

Sayre, Anne. *Rosalind Franklin and DNA*. W.W. Norton & Company, 1975.

Sayre was Rosalind's close friend, providing interesting insights into what she was like both outside of work and away from family. Sayre's inspiration for the biography was a response to Watson's autobiography *The Double Helix* which portrays Rosalind as the villain. While we did find her remarks on the state of segregation at King's to be likely overstated based on our research, her bibliography was of tremendous use. Sifting through the works cited, we happened to see an interview Sayre had with Crick in 1970. After reading it, we found the quote that Crick believed Franklin would have solved the structure in three months if Watson had not seen Photo 51.

Websites

65 years on from Photo 51. King's College London, 2017.
alumni.kcl.ac.uk/news-features/65-years-on-from-photo-51.

Not only is it vital to understand what Rosalind Franklin did, but it is also the impact that it had on our world. This website explains the importance of Photo 51 and what it has helped to do since it was taken. Because it was written 65 years after the picture, it offers a unique view of the significance of Photo 51.

Benderly, Lieff Beryl. "Rosalind Franklin and the Damage of Gender Harassment." *Science*, Science Magazine, Aug. 2018, <https://www.sciencemag.org/careers/2018/08/rosalind-franklin-and-damage-gender-harassment>.

This is an interesting article about how Rosalind Franklin was "gender harassed" within her work place by Wilkins and other male scientists. Within the article, there are several quotes by Watson and Crick that showed their sexist attitude towards Franklin. This article was helpful when determined if her gender played a significant role in her work relationships.

Cobb, Mathew. "Sexism in Science: Did Watson and Crick really Steal Rosalind Franklin's Data?" *The Guardian*, The Guardian, Jun. 2015, <https://www.theguardian.com/science/2015/jun/23/sexism-in-science-did-watson-and-crick-really-steal-rosalind-franklins-data>.

This article has a lot of information that opposes conclusion that we come to in our documentary. It is interesting to see conflicting opinions, and it is vital to learn about both sides of the story. However, some of the information in this is biased and can be seen as unreliable since it is based upon the accounts of people that disliked Franklin and saw her as a scientific threat.

"The Discovery of DNA." *Yourgenome*, Yourgenome, <https://www.yourgenome.org/stories/the-discovery-of-dna>.

This was a very interesting source that focused on the history of discovering DNA and structure of it. Instead of talking only about Watson and Crick, it gives credit to several historical scientists that provided the vital stepping stones toward the incredible discovery of the helical structure of DNA.

Elkin, Lynne. "*Rosalind Franklin and the Double Helix*." *Physics Today*, 1 Mar. 2003. doi.org/10.1063/1.1570771.

This article gives a modern-day overview of Franklin's life and triumphs. When researching, it is important to find many sources: when the sources agree, we can conclude the information is accurate. This is the case with this source. Not only did it have vital information about Franklin, but it also gave another source for cross-referencing. We used this article when talking about Franklin's remarkable work on coal, work so important it is still cited today.

“ESA's Mars Rover Has a Name – Rosalind Franklin.” *European Space Agency*, European Space Agency, 7 Feb. 2019,
www.esa.int/Our_Activities/Human_and_Robotic_Exploration/Exploration/ExoMars/ESA_s_Mars_rover_has_a_name_Rosalind_Franklin.

This website was about the European Space Agency naming its Mars space rover after Rosalind Franklin. The article shows the huge footprint that Rosalind Franklin had on society, and how the world is finally starting to recognize Rosalind Franklin and her contributions. We used this article to illustrate Franklin’s impact and why her story is so important.

Fara, Patricia. *Rosalind Elsie Franklin (1920-58)*. The Rosalind Franklin Institute.
www.rfi.ac.uk/about/rosalind-franklin/.

Dr. Patricia Fara, whom we interviewed, wrote this wonderful online biography. When researching someone, it is vital to look at as many different sources from as many different places as possible. This source gave another way to view Franklin and her work because it told about Franklin’s life and what she found interesting during her professional career.

Guide to Understanding X-ray Crystallography. UCLA Chemistry and Biochemistry.
www.chem.ucla.edu/~harding/ec_tutorials/tutorial73.pdf.

X-ray crystallography, a subject in which Franklin was adept, was an invaluable asset during the race to discover the structure of DNA. This document helped us to understand the way that it works so we could better explain it in the documentary. By understanding the complexity of X-ray crystallography, we were able to shorten the explanation as well as understand how remarkable Franklin and her diffractions were.

“James Watson, Francis Crick, Maurice Wilkins, and Rosalind Franklin.” *Science History Institute*, Science History Institute, Dec. 2017
<https://www.sciencehistory.org/historical-profile/james-watson-francis-crick-maurice-wilkins-and-rosalind-franklin>.

With such a great impact, the people associated with the DNA discovery have a lot of information about them. This article provides information about each individual as well as them as a whole, which was interesting to read about. This article was used to cross reference other information, as well as expand on several ideas.

Johnson, Ban. *Rosalind Franklin's contributions to virology*. Nature Microbiology, 25 Jul 2017. naturemicrobiologycommunity.nature.com/users/17778-ben-johnson/posts/18900-rosalind-franklin-s-contributions-to-virology.

With so much written about Franklin and her work on DNA, this source became very important because it speaks of Franklin's triumphs in virology and how they affected the scientific world. In our documentary, we used this source to speak of Franklin's work in virology and emphasize that she had an amazing impact on the world.

Lee, Jane J. "6 Women Scientists Who Were Snubbed Due to Sexism." *National Geographic*, National Geographic Magazine, May 2013, <https://news.nationalgeographic.com/news/2013/13/130519-women-scientists-overlooked-dna-history-science/>.

This article published by the National Geographic Magazine offers several women scientists that have been overlooked. Within the article is a part about Rosalind Franklin, which provides an amazing synopsis about how terribly unjust it was for Franklin to not receive recognition. While it is amazing that more people are starting to recognize her for her amazing work and impacts, there is still a long way to go to destroy the false myths surrounding her story.

Lloyd, Robin. "Rosalind Franklin and DNA: How Wronged was She?" *Scientific American*, Scientific American, Nov. 2010, <https://blogs.scientificamerican.com/observations/rosalind-franklin-and-dna-how-wronged-was-she/?redirect=1>.

The idea of a sexist environment in King's College, London, isn't new. In fact, it was something that could be seen by simply the condescending things said about Franklin. However, this article disagrees with that idea, stating that Franklin did get recognition for her work. Of course, it is vital to understand both sides of the story, but it is near impossible to consider Franklin as justly credited for the amount of research and experiments she did.

Maurice Wilkins and Rosalind Franklin. King's College London.

www.kcl.ac.uk/aboutkings/history/famouspeople/wilkinsfranklin.aspx.

Maurice Wilkins was Rosalind Franklin's lab associate at King's. The fact that there was a lot of dissension between them made it vital that we gained insight into Wilkins' view of her. This article from King's College allows us to understand who Wilkins was and helped us know more about the people that Franklin and Wilkins worked with, like Gosling.

The Nobel Prize for Physiology or Medicine 1962. The Nobel Prize.

www.nobelprize.org/prizes/medicine/1962/summary/.

In 1962, six years after Franklin's tragic death, The Nobel Prize for Physiology or Medicine was awarded to Watson, Crick, and Wilkins "for their discoveries concerning the molecular structure of nucleic acids and its significance for information transfer in living material." Because the Nobel Prize cannot be awarded after death, Franklin was left out of this. We use this in our documentary to illustrate that if Franklin had lived until then she may have won the prize.

The Oswald T. Avery Collection: Biographical Information. NLM.

profiles.nlm.nih.gov/ps/retrieve/Narrative/CC/p-nid/35.

This National Library of Medicine article is about Oswald Avery and his scientific work. While our project is not about Avery, we found it useful to learn about him since he has such an influential part of DNA research. His tests suggested that DNA was responsible for heredity. We explain this in the documentary to introduce DNA.

"Rosalind Franklin." *Encyclopædia Britannica*, Encyclopædia Britannica, Apr. 2019,

<https://www.britannica.com/biography/Rosalind-Franklin>.

This article written by Britannica has some excellent biographical information about Rosalind Franklin. This was a great source for us to learn the basic information. It also helped us understand more about the story aspect of Franklin's life, more than her impacts and discoveries.

“Rosalind Franklin (1920-1958).” *Concept 19: DNA Molecule is Shaped Like A Twisted Ladder*, DNA From the Beginning, <http://www.dnafb.org/19/bio-3.html>.

This website gave valuable insight and another opinion on Rosalind Franklin. While researching a historical topic, it is vital to get as many different sources as possible to check the accuracy of any fact that may be put into the script.

“Rosalind Franklin: A Crucial Contribution.” *Nature News*, Nature Publishing Group, www.nature.com/scitable/topicpage/rosalind-franklin-a-crucial-contribution-6538012.

This article was a wonderful addition to the documentary, providing another opinion on Rosalind Franklin’s life, work and contribution to the scientific communities. The article also informed us of the thoughts that Franklin’s colleagues had of her. We used this article to highlight the fact that most of the people that knew Franklin saw her as a brilliant and kind scientist.

“Rosalind Franklin Biography.” *Biography.com*, A&E Television Networks, Apr, 2014, <https://www.biography.com/scientist/rosalind-franklin>.

This Biography told the story of Rosalind Franklin and how her work was unjustly shared by her colleague Wilkins. The article is very eloquent in sharing what happened on the fateful day that Watson visited King’s College. We used this source to help us further understand the impact of Rosalind Franklin, as well as the effect that Wilkins sharing Photo 51 had on the scientific community.

Royal Society Rosalind Franklin Award and Lecture. The Royal Society. royalsociety.org/grants-schemes-awards/awards/rosalind-franklin-award/.

The Rosalind Franklin award and lecture is an extraordinary example of Franklin’s impacts. The website explains about the award and lecture and has a list of people who have won the award. Franklin’s example is still encouraging people in science today.

Interviews

Collins, Francis. Personal interview. 30 May. 2019.

Dr. Francis Collins is the Director of the National Institute of Health (NIH). The NIH is the largest biomedical research center in the world and they use DNA every day. Dr. Collins explained how vital Franklin's discovery was, as well as what that discovery allowed scientists to do today. He shared the fact that, even as a brilliant and intelligent scientist, she was not respected because she was a stubborn woman in science at a time which women were not accepted in science. Dr. Collins also played his song "Amazing DNA" on his unique DNA guitar named Rosalind. Collins added a new verse in this version, giving Franklin the highest credit for the amazing double helix discovery.

Crick, Francis. Interview by Anne Sayre. 16 June 1970. Documented in *Rosalind Franklin and DNA*, W.W. Norton & Company, 1975.

This interview with Francis Crick presents his view of the events that lead up to the discovery of DNA. In this interview Crick shares some insight as to how close Franklin was to discovering the structure of DNA. We use this in our documentary to showcase that if Watson had not seen Franklin's work, Franklin would have probably been the one to officially discover the structure of DNA.

Holland, Laura. Personal Interview. 19 Dec 2018.

Laura Holland is the director of communications at the Rosalind Franklin Institute. In this interview, Holland speaks of how Franklin's scientific career is what they are trying to 'echo.' Their goal is to honor the memory of Franklin by continuing her work and by bridging several sciences. By doing this, more can be learned about biology, and eventually, science and life.

Klug, Aaron. Interview by Ken Homes. 10 Aug 2017.

www.youtube.com/watch?v=hj82HUS-e_I&list=PLVV0r6CmEsFy8Dwcp3nOeTAWKehW9bupo.

This interview with Aaron Klug, who was one of Franklin's closest friends, is critical in understanding Franklin as a person. It also helped us understand that Franklin enjoyed her work at Birkbeck College. Klug explained that he won a Nobel Prize in 1982 for work he started with Franklin. Another time Franklin could have won the Nobel Prize if she had not died so young.

Riley, Andrew and Patricia Fara. Personal interview. 18 Dec 2018.

This interview with Dr. Fara and Andrew Riley was both friendly and informative. They provided insight into what is happening with Franklin's legacy, including her nomination to be on the new £50 note. They explained that she has the same level of national fame as Stephen Hawking, and provided other examples of how she is typically remembered.

Maddox, John. Interview. Documented in "Secret of Photo 51" Boston, MA: WGBH Boston Video, 2003.

John Maddox was the editor of the journal *Nature* after the famous announcement of the discovery of DNA. This interview with John Maddox showed us that while John Watson and Francis Crick mentioned Franklin in passing, they actually knew much more about Franklin and her work. John Maddox emphasizes that Watson and Crick did not credit Rosalind. Maddox calls the time Watson used Franklin's work without her permission rat-like. We use it in the documentary to show the tragic truth, that Watson and Crick barely gave any credit to Franklin's work, even though they based most of their work on Franklin's research.

Platt, Jamie. Personal Interview. 11 Jan 2019.

Dr. Platt is a geneticist who specializes in precision medicine (and also A.J.'s mother). Dr. Platt explained to us that her entire field of work was made possible by Franklin's experiments and that Franklin's approach to science was much how it ought to be. Whereas Watson and Crick conducted trial and error on models until one worked, it was Franklin who produced the data and began interpreting. It is no wonder Watson, Crick, Wilkins, and Pauling had all produced several possible structures without any success: without data, they could not prove it was correct. It also comes as no shock that Franklin's data was required to produce an accurate model. Dr. Platt also verified the scientific accuracy of our film.

Thomson, Anne. Personal Interview. 18 Dec 2018.

The interview with Anne Thomson was extremely helpful, as it helped us understand Franklin's amazing impact. When we spoke with her we learned that a building at Newnham College, Cambridge is named after Franklin. This impact may not seem like a lot, but it is a testament to how much she did. Franklin changed science forever.

Videos

Glassman, Gary, and Sigourney Weaver. *Secret of Photo 51*. Boston, MA: WGBH Boston Video, 2003.

This NOVA documentary on Rosalind Franklin's life provided many things of use: animations which we could borrow, displays of primary sources we could not otherwise obtain, and interviews with the likes of Aaron Klug, Raymond Gosling, and Maurice Wilkins who have passed away recently. It did yield important perspectives from the other characters in the story of the race to discover DNA.

Guerra, Cláudio L. *Rosalind Franklin: DNA's Unsung Hero*. Ted-Ed, 11 July 2016.
www.youtube.com/watch?v=BIP0IYrdirI.

Today many people see Franklin as an unsung hero and while she is, that is not all she should be remembered for. She was a hero, but she also did not care to be singled out as special. All Franklin wanted was to be treated equally in her workplace. This video allowed us to see how people perceived Franklin. It also helped us understand some of Franklin's more heroic work. We first learned of her experiments on coals, which saved lives during World War II, from this video.

Music

Holst, Gustav. "The Planets - II. Venus, the Bringer of Peace." *The Planets*,
Jurowski, Vladimir and London Philharmonic Orchestra, London Philharmonic
Orchestra, 22 May 2009, 2.

This is the music we use in the background of the documentary. It was written by Rosalind Franklin's music teacher, who had stated that Franklin had no musical talent. This was a unique connection that we decided to use because the music was so creative and it added a piece of Franklin's childhood that we would have otherwise omitted. We considered using Franklin's favorite song, however we found that Franklin considered music ridiculous, which resulted in no favorite song to use.

Collins, Francis. "Amazing DNA." Collins, Francis, 30 May. 2019.

Dr. Francis Collins' song "Amazing DNA" has a very interesting story behind it. During our interview, he played this song for us which included a unique verse about Rosalind Franklin. This is the first and only recording of this new verse. We see this song as another wonderful impact of Franklin, which is why we decided to use it in the credits section of our documentary.