Lesson Plan
Eunice Foote: Climate Scientist

An illustration of Eunice Newton Foote collecting observations for her groundbreaking atmospheric research.

Illustration by Carlyn Iverson

Grade Level(s): 6-8, 9-12	**Subject(s): Physics, History, Earth Science**

Supplements: Physics Topic

In-Class Time: 95-135 minutes	**Prep Time: 15-20 minutes**

Materials

- A/V Equipment
- Internet Access
- Copies of Foote vs Tyndall (found in Supplemental Materials)
- Copies of Discussion Questions (found in Supplemental Materials)
- Devices that have internet access for researching and creating presentations

Objective

Until 2011, Eunice Newton Foote did not receive credit for her 1856 discovery of the greenhouse effect of carbon dioxide. In this lesson, students will learn about her research, the historical context she performed her research in, and the implications of her discovery on climate and global warming. Students will watch a video replicating her experiment and learn the science behind the greenhouse

effect. (For recreating Foote's experiment in the lab, see the teaching guide "Eunice Foote and the Greenhouse Gas Effect.") They will also read and discuss why John Tyndall, who came to the same conclusion as Foote three years later, received credit for her discovery. At the end of the lesson, students will explore the implications of the greenhouse effect for climate change and other related fields.

Introduction

Eunice Newton Foote (1819-1888) was a scientist, inventor, and women's rights activist who first discovered carbon dioxide's ability to retain heat and concluded that an increase in the presence of carbon dioxide in the atmosphere would cause global warming. Today, we call this the greenhouse effect and though Foote discovered it in 1856, she did not receive credit for her discovery until 2011.

Very little is known about Eunice Foote's early life. Her father was Isaac Newton Jr. of Bloomfield, New York, her mother unknown.[1] She attended Troy Female Seminary, an all-girls school and took classes at a nearby men's science college, now known as Rochester Polytechnic Institute. Though she never received any specific physics education, she was trained in general science which no doubt aided her future scientific endeavors. In 1841, she married Elisha Foote a mathematician, inventor, and judge.[2] They were both women's rights activists and attended the 1848 Seneca Falls convention, credited for sparking the women's rights movement. Together they had two daughters, Mary Newton Henderson and Augusta Newton Arnold.[3]

As a scientist, Eunice Foote was groundbreaking. Though she published just two papers, she was one of the first female scientists published in the United States.[4] Her first paper, "Circumstances Affecting the Heat of the Sun's Rays," was published in 1856 and covered her experiment to test how different atmospheric conditions such as air density, humidity, and gases respond to heat from the sun. Her discovery in this paper, that carbon dioxide absorbs and retains heat significantly more than the other conditions is what we know today as the greenhouse effect.[5] Her second paper, "On a New Source of Electrical Excitation," was published in 1858 and addressed how varying moisture content effects the static electricity in the air.[6] In addition to conducting scientific research, Foote was also an inventor and held the patent for a shoe filling.[7]

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[1] Reed, Elizabeth W. *American Women in Science Before the Civil War*. Minneapolis, 1992.
[2] Joseph D. Ortiz and Ronald Jackson. "Understanding Eunice Foote's 1856 Experiments: Heat Absorption by Atmospheric Gases." *Notes and Records: The Royal Society Journal for the History of Science* (26 August 2020), 1-18. https://doi.org/10.1098/rsnr.2020.0031.
[3] Reed, *American Women in Science Before the Civil War*.
[4] Ortiz and Jackson, "Understanding Eunice Foote's 1856 Experiments," 1-18.
[5] Eunice N. Foote, "On the Heat in the Sun's Rays," *The American Journal of Science and Arts* 22 (November 1856): 377–82.
[6] Eunice N. Foote, "On a New Source of Electrical Excitation," *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 15, no. 99 (1858): 239–40. https://doi.org/10.1080/14786445808642471.
[7] Eunice N. Foote, Filling for the soles of boots and shoes, US Patent Office US28265A (Saratoga Springs, NY, 1860).

Foote's atmospheric experiments were likely motivated by an interest in the geologic past. At the time, scientists were confused why areas of higher elevation contained evidence of plants and animals found in warmer environments and speculated of a warmer past.[8] To explore what changes to the atmosphere could foster a warmer environment, Foote recreated different atmospheric conditions in glass jars and exposed them to the sun. She filled jars with common air, pumping in more air or removing some to compare different densities, adding moisture to others, or even different gases like carbon dioxide. She measured the difference in temperature of the jars in sunlight and a control jar of each gas left in the shade. Based on her observations, she concluded that higher pressure air, damp air, and some gases are more affected by the sun's rays than common air, the most dramatic effect from carbon dioxide.[9] Though Foote did not account for *how* the gases cause climate change, understood now to be the invisible infrared wavelengths of light that radiate off Earth's surface in the form of heat, she was the first to recognize the gas's ability to absorb heat its implications.[10]

Criticism for her work lies in the limitations of its scope. She measured the heating of different atmospheric conditions without attempting to speculate the causes for heating.[11] Though her conclusions were indisputably accurate, the precise mechanism she believed to cause heating, direct sunlight, is not the cause of the greenhouse effect. Instead, it is the heat radiating off the Earth's surface as invisible infrared radiation that gets trapped by greenhouse gases and causes the Earth's temperature to rise. Though Foote likely was not measuring the effect of infrared bands on carbon dioxide, she did recognize the gas's potential for absorbing heat.[12]

Despite wider recognition than many female U.S. scientists before her, her work received little attention compared to her male counterparts. Comparing the reception of her work to her husband's is a case study in the unequal treatment she received. Both of their research was presented at the 10th American Association of the Advancement of Sciences (AAAS) meeting in 1856. Like most researchers, Elisha Foote presented his own findings, while Eunice's paper was presented by Joseph Henry, then Secretary of the Smithsonian institution. That year, Elisha but not Eunice Foote was voted as a member of AAAS.[13] Henry's coverage and remarks on Eunice Foote's work was published by the *American Journal of Science and Arts* and covered by *Scientific American* in an article about skilled female scientists,[14] but it received little coverage outside of that. It is likely that few at the time understood the wider implications of her discovery, but it is also likely that the minimal coverage and subpar treatment was due to Eunice Foote's gender. In 1859, just three years after Foote's findings were published, the Irish scientist John Tyndall arrived at the same conclusion that variations in atmospheric gases absorb radiation differently and contribute to climate change. He was probably unaware of Foote's work and

[8] Ortiz and Jackson, "Understanding Eunice Foote's 1856 Experiments," 1-18.
[9] Foote, "On the Heat in the Sun's Rays," 377–82.
[10] Ortiz and Jackson, "Understanding Eunice Foote's 1856 Experiments," 1-18.
[11] Foote, "On the Heat in the Sun's Rays," 377–82.
[12] Ortiz and Jackson, "Understanding Eunice Foote's 1856 Experiments," 1-18.
[13] Ibid.
[14] "Scientific Ladies--Experiments with Condensed Gases," *Scientific American* 12, no. 1 (13 September 1856): 5.

was credited with the discovery of the greenhouse effect for a century and a half. In 2011, geophysicist Raymond Sorenson rediscovered her work and brought her research back into the public eye.[15]

Instructions/Activities

Engage: 5-10 Minutes

Teachers will introduce topic by discussing the weather, option to use *Suggested Opening Questions* found in Supplemental Materials.	
What is the teacher doing? Leading a discussion with the class to kept them thinking about weather and atmospheric heating.	**What are the students doing?** Discussing the questions.

Explore: 15-20 Minutes

Students will read Foote vs Tyndall to learn about Eunice Newton Foote's work and why she did not receive credit until 2011. The teacher will provide students with Discussion Questions.	
What is the teacher doing?	**What are the students doing?**
Provide students copies Foote vs Tyndall. Use the version with the reading level appropriate for your students.	Receive and read the copy of Foote vs Tyndall
Provide students with copies of the Discussion Questions (found in the Supplemental Materials). Instruct students to answer them as they read through the documents.	Answer the Discussion Questions provided by the teacher as the reading is completed.
If desired, collect the answers to the Foote vs. Tyndall questions for evaluation.	If instructed, submit answers to the Foote vs. Tyndall Questions to the teacher for evaluation.

Explain: 25-35 Minutes

The teacher will review and discuss the answers to the Foote vs Tyndall Discussion Questions. The teacher will show the videos on the Greenhouse Effect and Climate Change and lead discussion. The video "Climate 101 with Bill Nye" is for Middle School and early High School students. The video "How do Greenhouse Gases Actually Work?" can be added for older students. The teacher will also return to the opening questions about weather and discuss what the class learned. The suggested discussion questions below are also available in a supplementary document.

1. CLIMATE 101 with BILL NYE suggested questions:
    a. What is the purpose of having a "scientific control" in an experiment?
        i. The "control" reduces error by isolating the experimental factor. Because all the variables in the control are kept constant, an experimenter can compare the control to the effects of changing an independent variable.

[15] Raymond P. Sorenson "Eunice Foote's Pioneering Research on CO_2 And Climate Warming," *Search and Discovery*, no. #70092 (31 January 2011).

b. In the demonstration with the glass jars, which jar is the "control" - common air or increased carbon dioxide? And what is the independent variable being tested?
    i. The jar with increased carbon dioxide because carbon dioxide is the independent variable
c. Ask the students to identify how the experimenter reduced experimental errors to isolate the effect of the independent variable (carbon dioxide concentration)?
    i. By ensuring the jars are the same type of bottle, temperature, initial condition before adding CO_2, the same temperature probes, the same heat lamps at the same distance
d. Why are greenhouse gases sometimes good?
    i. They help regulate Earth's temperature, without them it would get cold without the sun out
e. What are negative factors of increased carbon dioxide?
    i. Global warming, sea level rise, dramatic weather events

2. How Do Greenhouse Gases Actually Work?
    a. What helps regulate temperature on the Earth in comparison to the moon?
        i. The Earth's atmosphere
    b. Infrared radiation is an electromagnetic wave (light) but it is also called what other name?
        i. Heat
    c. How do molecules absorb heat?
        i. When molecules are electrically charged, they can absorb radiation. This can happen because they're charge distribution is lopsided (water vapor) or because they are being knocked around in a way that changes their charge distribution
    d. What two gases make up most of the atmosphere and are they greenhouse gases?
        i. Nitrogen and oxygen. They are not greenhouse gases.

What is the teacher doing?	**What are the students doing?**
Show the video(s) to the students and lead a discussion on the information presented using suggested questions.	Watch the video(s) and participate in discussion.

Elaborate: 20-30 Minutes for making presentation
30-45 Minutes for presentations depending on number of groups.

In this section, students will pursue related areas of interest to understand the significance of Eunice Foote's work. They will present to the class about their research.

What is the teacher doing?	**What are the students doing?**
The teacher provides student's options for their further research in tangential fields. Below is a list of suggested topics: • Climate trends over Earth's history	Students use the internet to research a short (under five minute) presentation on a topic related to Eunice Newton Foote's work. They could work independently or in groups.

• Major greenhouse gas emitters • Politics surrounding climate legislation • Ways people can reduce their carbon footprint • Effects of climate change on sea-level rise • Other notable climate scientists • Meteorological trends • Exoplanet atmospheres (see https://exoplanets.nasa.gov/alien-worlds/strange-new-worlds/ for interesting exoplanets)	Students will give their presentations in the same class period or a later one.

Evaluate:

The teacher could evaluate the students' presentations or their responses to the discussion questions.

Required/Recommended Reading and Resources

Video

- MinuteEarth. "How Do Greenhouse Gases Actually Work?" YouTube video, 3:08 minutes. Posted May 2015. https://www.youtube.com/watch?v=sTvqIijqvTg
- Climate Reality. "CLIMATE 101 with BILL NYE" YouTube video, 4:33 minutes. Posted September 2011. https://www.youtube.com/watch?v=3v-w8Cyfoq8

Readings

- "Foote vs Tyndall." June 2021. Available in Supplementary Documents.

Discussion Questions

Suggested Opening Questions:

1. Describe the weather outside today?
2. What is everyone's favorite weather?
3. Have you noticed that the heat is worse when it is humid outside too?
4. Why might areas of higher elevation, such as mountains, be colder than areas of low elevation?
5. Why do you think summer nights remain warm, even though the sun goes down?

Foote vs Tyndall Questions:

1. What is the Greenhouse Effect? What gas did Foote and Tyndall discover causes it?
2. How did Foote's experiment differ from Tyndall's?
3. What factors lead Tyndall to receive credit as the discoverer of the Greenhouse Gas effect?
4. Why is it important that Foote receive credit for her discovery?

Further Reading and Additional Resources

- Foote, Eunice N. "On the Heat in the Sun's Rays." *The American Journal of Science and Arts* 22 (November 1856): 377–82.

- "Scientific Ladies--Experiments with Condensed Gases." *Scientific American* 12, no. 1 (September 13, 1856): 5.
- Joseph D. Ortiz, and Ronald Jackson. "Understanding Eunice Foote's 1856 Experiments: Heat Absorption by Atmospheric Gases." *Notes and Records: The Royal Society Journal for the History of Science* (26 August 2020), 1-18. https://doi.org/10.1098/rsnr.2020.0031.
- Sorenson, Raymond P. "Eunice Foote's Pioneering Research On CO2 And Climate Warming." *Search and Discovery*, no. #70092 (January 31, 2011). https://www.searchanddiscovery.com/pdfz/documents/2011/70092sorenson/ndx_sorenson.pdf.html.
- Jackson, Ronald. "Eunice Foote, John Tyndall and a Question of Priority." *The Royal Institution* 74, no. 1 (February 13, 2019): 105–18. https://doi.org/10.1098/rsnr.2018.0066.

Extensions

History Research Activity

Eunice Foote focused primarily on advancing women's rights after her two papers were published. She attended the Seneca Falls Convention which sparked the women's rights movement and inspired many women to seek the right to vote. Students can research other suffragists and write a short paper or make a presentation about their life and work.

Suggested research topics include: Elizabeth Cady Stanton, Alice Paul, Lucy Stone, Ida B Wells, Frances E.W. Harper, Mary Church Terrell, Sojourner Truth, Lucretia Mott, Amelia Bloomer, and Mary McLeod Bethune.

For further information on this activity, see the related teaching guide "Eunice Foote: Scientist and Suffragist."

Science Activity

Students can delve more into the science of gasses by recreating Eunice Newton Foote's historic experiment. For further information on this activity, see the related teaching guide Eunice Foote and the Greenhouse Gas Effect.

Related AIP Teacher's Guides on the History of the Physical Sciences:
Eunice Foote: Scientist and Suffragist
Eunice Foote and the Greenhouse Gas Effect
Scientific Writing in the Chemical and Earth Sciences

Common Core Standards

For more information on Common Core Standards, visit http://www.corestandards.org/.

Speaking & Listening	
CCSS.ELA-LITERACY.SL.6.1	Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 6

	topics, texts, and issues, building on others' ideas and expressing their own clearly.
CCSS.ELA-LITERACY.SL.6.2	Interpret information presented in diverse media and formats (e.g., visually, quantitatively, orally) and explain how it contributes to a topic, text, or issue under study.
CCSS.ELA-LITERACY.SL.6.4	Present claims and findings, sequencing ideas logically and using pertinent descriptions, facts, and details to accentuate main ideas or themes; use appropriate eye contact, adequate volume, and clear pronunciation.
CCSS.ELA-LITERACY.SL.7.1	Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 7 topics, texts, and issues, building on others' ideas and expressing their own clearly.
CCSS.ELA-LITERACY.SL.7.2	Analyze the main ideas and supporting details presented in diverse media and formats (e.g., visually, quantitatively, orally) and explain how the ideas clarify a topic, text, or issue under study.
CCSS.ELA-LITERACY.SL.7.4	Present claims and findings, emphasizing salient points in a focused, coherent manner with pertinent descriptions, facts, details, and examples; use appropriate eye contact, adequate volume, and clear pronunciation.
CCSS.ELA-LITERACY.SL.8.1	Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others' ideas and expressing their own clearly.
CCSS.ELA-LITERACY.SL.8.4	Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation.
CCSS.ELA-LITERACY.SL.9-10.1	Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 9-10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
CCSS.ELA-LITERACY.SL.9-10.4	Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task.
CCSS.ELA-LITERACY.SL.11-12.1	Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 11-12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
CCSS.ELA-LITERACY.SL.11-12.4	Present information, findings, and supporting evidence, conveying a clear and distinct perspective, such that listeners can follow the line of reasoning, alternative or opposing perspectives are addressed, and the organization, development, substance, and

	style are appropriate to purpose, audience, and a range of formal and informal tasks.
History/Social Studies	
CCSS.ELA-LITERACY.RH.6-8.1	Cite specific textual evidence to support analysis of primary and secondary sources.
CCSS.ELA-LITERACY.RH.6-8.2	Determine the central ideas or information of a primary or secondary source; provide an accurate summary of the source distinct from prior knowledge or opinions.
CCSS.ELA-LITERACY.RH.9-10.1	Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
CCSS.ELA-LITERACY.RH.9-10.2	Determine the central ideas or information of a primary or secondary source; provide an accurate summary of how key events or ideas develop over the course of the text.
CCSS.ELA-LITERACY.RH.11-12.1	Cite specific textual evidence to support analysis of primary and secondary sources, connecting insights gained from specific details to an understanding of the text as a whole.
CCSS.ELA-LITERACY.RH.11-12.2	Determine the central ideas or information of a primary or secondary source; provide an accurate summary that makes clear the relationships among the key details and ideas.
Subject Writing (applicable for the Extension Activity)	
CCSS.ELA-LITERACY.WHST.9-10.1	Write arguments focused on *discipline-specific content*.
CCSS.ELA-LITERACY.WHST.9-10.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
CCSS.ELA-LITERACY.WHST.9-10.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
CCSS.ELA-LITERACY.WHST.9-10.5	Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
CCSS.ELA-LITERACY.WHST.9-10.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
CCSS.ELA-LITERACY.WHST.9-10.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

CCSS.ELA-LITERACY.WHST.9-10.9	Draw evidence from informational texts to support analysis, reflection, and research.
CCSS.ELA-LITERACY.WHST.11-12.1	Write arguments focused on *discipline-specific content*.
CCSS.ELA-LITERACY.WHST.11-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.
CCSS.ELA-LITERACY.WHST.11-12.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
CCSS.ELA-LITERACY.WHST.11-12.5	Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
CCSS.ELA-LITERACY.WHST.11-12.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
CCSS.ELA-LITERACY.WHST.11-12.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
CCSS.ELA-LITERACY.WHST.11-12.9	Draw evidence from informational texts to support analysis, reflection, and research.
Science and Technical Subjects	
CCSS.ELA-LITERACY.RST.6-8.1	Cite specific textual evidence to support analysis of science and technical texts.
CCSS.ELA-LITERACY.RST.6-8.2	Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.
CCSS.ELA-LITERACY.RST.9-10.1	Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
CCSS.ELA-LITERACY.RST.9-10.2	Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-LITERACY.RST.11-12.2	Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

Next Generation Science Standards

For more information on the Next Generation Science Standards, visit http://www.nextgenscience.org/.

Earth's Systems	
HS-ESS2-4 Earth's Systems	Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. Grade: High School (9-12)
Earth and Human Activity	
MS-ESS3-5 Earth and Human Activity	Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century. Grade: Middle School (6-8)