THE INS AND OUTS OF A CLIMATE FEEDBACK LOOP

DESCRIPTION

Students learn how increasing atmospheric carbon dioxide is warming Earth's climate. They use the National Oceanic and Atmospheric Administration (NOAA) Interactive Atmospheric Data Visualization tool to investigate atmospheric carbon dioxide locally, conduct an experiment to model the greenhouse effect, and examine a positive feedback loop.

PHENOMENON

Carbon dioxide in the atmosphere is affecting temperatures on Earth, resulting in several positive feedback loops.

GRADE LEVEL

9-12

OBJECTIVES

Students will:

- Use models to generate data to support a scientific explanation
- Model the greenhouse effect
- Analyze the results of an experiment to provide evidence for a phenomenon
- Examine a positive feedback loop and explain how the inputs are destabilizing

TIME

1 HOUR FOR OPTION 1
45 MINUTES FOR OPTION 2

COMMON CORE STATE STANDARDS

English Language Arts

CCSS.ELA-LITERACY.W.9-10.1.E. Provide a concluding statement or section that follows from and supports the argument presented.

CCSS.ELA-LITERACY.RST.9-10.3. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS.ELA-LITERACY.RST.9-10.4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.

Math

CCSS.MATH.CONTENT.HSN.Q.A.2. Define appropriate quantities for the purpose of descriptive modeling.

CCSS.MATH.CONTENT.HSS.ID.A.2. Use statistics appropriate to the shape of the data distribution to compare center (median, mean) and spread (interquartile range, standard deviation) of two or more different data sets.

NEXT GENERATION SCIENCE STANDARDS

Performance Expectation

HS-ESS2-2 Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Analyzing and Interpreting Data	ESS2.A: Earth Materials and Systems ESS2.D: Weather and Climate	Systems and System Models Stability and Change

BACKGROUND

The greenhouse effect keeps heat that radiates from the Earth's surface inside the atmosphere, ensuring that the planet is warm enough to sustain life. Since the Industrial Revolution, humans have been emitting increasing amounts of greenhouse gases into the atmosphere, mostly through energy production, transportation, and industry. Humans release more carbon dioxide than any other greenhouse gas. As additional carbon dioxide is released into the atmosphere, more of the thermal energy radiating from Earth is re-emitted back to the planet instead of escaping into space.

A greater concentration of atmospheric carbon dioxide and other greenhouse gases is causing average global temperatures to increase, forming several positive feedback loops. In the example in this activity, thermal expansion of water in the oceans is occurring, and ice sheets and glaciers are melting, which together are causing sea level rise. Rising sea levels are resulting in the destruction of coastal wetlands, such as tidal marshes and mangroves. Coastal wetlands are very effective at sequestering carbon, and with their destruction, atmospheric carbon dioxide will increase. In other words, the destruction of coastal wetlands magnifies the effect of the initial change, increasing carbon dioxide, resulting in a positive feedback loop.

MATERIALS

- Copies of The Ins and Outs of a Climate Feedback Loop handout [1 per student]
- PowerPoint presentation
- Computer and projector for educator
- Computers or tablets with internet access [1 per every 1-3 students]
  - If computers or tablets for students are not available, see options in Increasing Carbon Dioxide, Section 1
- Binder clips, size small (¾" wide) [1 per every four students]
- Calculators [1 per every four students or more if available]
- Hand towels (16" x 26" or larger) [1 per every four students]
  - If working with adults or older students, may also want a few small bath towels (27" x 52" or smaller)
- Mylar space/emergency blanket (Figure 1), cut into rectangles of approximately 20" x 26" or larger if needed [1 per every four students]
- Stopwatches [1 per every four students]
- Thermometers*, preferably ones with a probe and separate digital readout, such as the meat thermometer shown in Figure 2 [1 per every four students]
- *The Ins and Outs of a Climate Feedback Loop* instructional video, optional introduction to the experiment for the instructor

Figure 1. Example Mylar emergency/space blanket

Figure 2. Example meat thermometer with probe and digital readout

***Some notes about thermometers:**

- A thermometer without a probe and digital readout can be used. However, students will not be able to check the temperature readings every minute as instructed in this activity because they would have to lift the towel to read the thermometer, which would release the trapped heat. Instead, if using a thermometer without a probe, students should **only** read and record the temperature of the test subject's lap before placing the towel on top and after 5 minutes, immediately after removing the towel.
  - If a different type of thermometer is used, an alternative method of fastening the thermometer to the clothing on students' laps may be needed.
  - If a different type of thermometer is used, it is recommended that the educator try the experiment using their own lap several times before conducting the activity with students.
- Another option is an indoor-outdoor thermometer with a digital readout and wired sensor (such as the one found here: www.acurite.com/indoor-outdoor-thermometer-with-probe.html). However, in our testing of an indoor-outdoor thermometer, it seemed slower to respond and register changes in temperature, and students may not see as large of a temperature difference.

PREPARATION

You may choose the Full Lesson or Abbreviated Lesson based on time and technology constraints. The Full Lesson requires 1 hour and works best with an internet-connected computer or tablet for every 1-3 students (if computers or tablets for students are not available, see options in Increasing Carbon Dioxide, Section 1). The Abbreviated Lesson takes 45 minutes and does not require student computers or tablets.

Option 1: Full Lesson

1. Turn on internet-connected computers or tablets [1 for every 1-3 students].
2. On each device, open a web browser and display the NOAA Interactive Atmospheric Data Visualization website: https://www.esrl.noaa.gov/gmd/dv/iadv/ [You may use this shorter URL if entering manually: https://bit.ly/2q4t5Pw]

Option 2: Abbreviated Lesson

(Also complete these steps for the Full Lesson)

3. If possible, watch the *Ins and Outs of a Climate Feedback Loop* instructional video for an introduction to the experiment.
4. For Part II of the Presentation, the Greenhouse Effect experiment, plan to divide students into teams of four. If necessary, teams of three or five would also be acceptable, as activity tasks can be combined or divided.
5. Plan locations for the appropriate number of stations needed to accommodate the number of student teams in the group. Stations can be at student desks or tables and chairs with enough space for three to five students. No power source is needed.
6. Place a small binder clip, calculator, stopwatch, thermometer, and towel at each station. Also place a rectangle of space blanket at half of the stations.
7. Draw the "Whole Class" table from The Ins and Outs of a Climate Feedback Loop handout on the board, or prepare to show it with a document camera.
8. Set up a computer and projector, and display the PowerPoint presentation.

PROCEDURES

Options 1 and 2: Full and Abbreviated Versions

Begin here for both Full Lesson and Abbreviated Lesson

INTRODUCTION

1. If time permits, show an attention-grabbing viral video.
2. **Slide 2**: what do viral videos and carbon dioxide have in common? [Click to make the graphic appear.] They're both part of feedback loops. In a feedback loop, one thing affects another, and then the effect "feeds back in" to the original cause. In our example, a video gets shared, and then more people see it. Because more people have seen it, it's now likely to get shared even more. Once it receives a large number of views in a short amount of time, it is considered viral.

Option 1: Full Version

Continue here for Full Lesson or skip to Abbreviated Lesson below.

INCREASING CARBON DIOXIDE

NOAA Interactive Atmospheric Data Visualization

1. The introduction includes a web-based data visualization of atmospheric carbon dioxide concentrations from several sites across the United States. Using the National Oceanic and Atmospheric Administration (NOAA) Interactive Atmospheric Data Visualization tool, students and/or educators will access the closest carbon dioxide monitoring site to their geographic location on an interactive map. When teaching this, choose one of the following options, depending on the availability of laptops or tablets with internet access.
   a. Students conduct the activity independently or in groups on devices with internet access (preferred method).
   b. The educator uses the instructions below and a projector or other screen to show the entire class as s/he conducts the activity on a single computer with internet access.
   c. The educator conducts the activity before class, using the instructions below, and makes copies of one or two graphs for students to analyze.
2. Pass out a The Ins and Outs of a Climate Feedback Loop handout to each student.
3. **Slide 3**: today, we will investigate how carbon dioxide in the atmosphere is affecting temperatures on Earth, resulting in several positive feedback loops. We will be using an online tool to examine the amount of atmospheric carbon dioxide at a nearby site, and then we will conduct an experiment to model the effects of carbon dioxide on global temperatures. Throughout the lesson, we will put together just one example of a positive feedback loop resulting from carbon dioxide, although there are several others. Do not let the name fool you. Positive feedback loops do not always result in positive effects.
4. **Slide 4**: we will start by using the NOAA Interactive Atmospheric Data Visualization (IADV) online tool look at the amount of carbon dioxide in the atmosphere at the closest nearby monitoring site.
5. **Slide 5**: follow the instructions on your handout to open the NOAA website, if it is not open already, and choose the closest monitoring site from the map.
6. **Slides 6-13**: depending on your preferences and students, you can choose to skip slides 6-13 and allow students to follow the instructions on the handout independently. Otherwise, use slides 6-13 to go over the student instructions:

a. **Slide 6**: open this website if it is not already open: https://bit.ly/2q4t5Pw
b. **Slide 7**: use the "+" symbol to zoom in on the area of the world where you live.
c. **Slide 8**: hover over and then click on the red dot that is closest to where you live. Red dots indicate active sites.
    i. **Slide 9**: ensure that the name of the sampling location that you would like to use (closest to where you live) is listed in the first drop down menu at the top of the page.
d. **Slide 10**: in the drop down menus near the top of the page:
    i. Find programs, and choose "Carbon Cycle Gases."
    ii. Leave the other two drop down menus on their default settings.
        1. Popup detail: "Full"
        2. Active Sites: "All Sites"
e. **Slide 11**: in the right side bar, click on the "Carbon Cycle Gases" button.
    i. Two or more plot types will appear.
        1. Click on "Time Series."
f. **Slide 12**: you will be taken to another screen. Leave all options on their default settings.
    i. Parameter: "Carbon Dioxide"
    ii. Data Type: "Flask Samples" or "Aircraft Data"
    iii. Data Frequency: "Discrete"
    iv. Time Span: "All – a graph of all available data"
    v. Click the "Submit" button.
g. **Slide 13**: use the graph to answer Analysis Questions 1 and 2 on your handout.
h. If you'd like to choose another site and time allows, click the "Site Selection" button next to the small globe icon on the right side of the screen under the top banner. Follow these instructions again to create another graph.

Option 2: Abbreviated Lesson

Begin here for Abbreviated Lesson and continue for Full Lesson.

1. **Slide 14**: the phenomenon that we're investigating today is that carbon dioxide is affecting temperatures on Earth, resulting in several positive feedback loops. Let's think about what a positive feedback loop is for just a moment.
    a. In positive feedback loops, one thing affects another, and the impact is amplified. An increase in one thing results in an increase in the next thing, which increases the first thing again, and so on.
    b. In the viral video example, a video gets shared, and then more people see it. Because more people have seen it, it's now likely to get shared even more. It's a positive feedback loop. Positive refers to how the increase in one factor leads to an increase in another factor. We are not using "positive" in the same sense as "good." In our example here, a video getting shared and more people seeing it could generally be viewed as positive, meaning that they are good. However, in our next example, the increases in the positive feedback loop lead to consequences that are not good for Earth's systems.
2. **Slide 15**: we're going to look at one example of a positive feedback loop in this lesson that relates to how increased carbon dioxide is affecting Earth's temperature, but there are several others. If you used the IADV online tool, you saw that carbon dioxide is increasing no matter what site was selected. Scientists have been measuring atmospheric carbon dioxide at Mauna Loa in Hawaii since 1958, and you can see that it has been increasing. Increasing atmospheric carbon dioxide is a good place to start to build our positive feedback loop. We will add more pieces of the feedback loop as we move through the lesson.

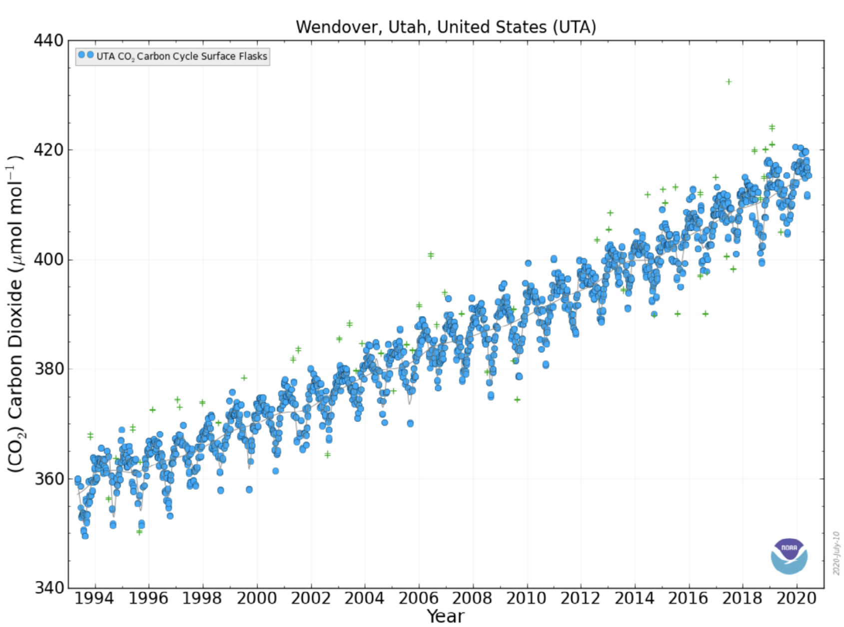

Figure 3. Example NOAA IADV graph from Wendover, UT

GREENHOUSE EFFECT

1. **Slide 16**: carbon dioxide is increasing in Earth's atmosphere. Let's think about why it matters with an experiment. Carbon dioxide is a greenhouse gas. We will conduct an experiment to model the effect of greenhouse gases on Earth's temperature.

2. Divide students into teams of four, and place students at stations.
3. Instruct students to read the team member roles on page 2 of the handout and choose one role for each student in the group.
4. **Slide 17**: the test subject will use a binder clip to attach the wire of the meat thermometer to the clothing on their lap. Instruct the student to point the metal probe toward their hip and attach the binder clip approximately halfway down the length of their thigh.
   a. (Figure 4). Ensure that the thermometer probe is contacting the student's thigh as much as possible. The probe should not be pointed sideways or hanging off of the student's lap.

Figure 4. Thermometer set up

5. The meat thermometer can take up to five minutes to accurately display the initial temperature of students' laps. Instruct students to watch the temperature casually and note whether it increases, decreases, or stays the same. Once students have their thermometers in place, take some time to explain the experiment and give a short introduction to the greenhouse effect as the thermometers adjust to their laps (steps 6-15).
6. Explain to the class that they will be conducting an experiment to determine which will insulate better: a single towel or a towel plus a space blanket on top. Tell students that the test subject in their group will place a towel over the thermometer and perpendicular to their thighs while demonstrating with one of the towels. Then, explain that half of the groups will also place a rectangle of space blanket on top while demonstrating with a towel and space blanket. Explain that the space blanket is made of Mylar, which is a good insulator (and also used for balloons), and it can be used as a blanket in emergencies. All groups will record the temperature every minute for five minutes.
7. Assign half of the student groups to conduct the "Towel Trial" and the other half of the student groups to conduct the "Towel + Space Blanket Trial." Instruct students to circle the trial that they have been assigned on page 2 of the handout.
8. Give a short introduction to the greenhouse effect using the PowerPoint presentation.
9. **Slide 18**: we have gases in our atmosphere that trap heat called greenhouse gases. They are: carbon dioxide, water vapor, ozone, methane, nitrous oxide, and fluorinated gases.
10. **Slide 19 (a)**: begin with the diagram on the left. The greenhouse effect ensures that Earth is warm enough for us to inhabit. Our atmosphere contains greenhouse gases, like carbon dioxide, methane, and nitrous oxide. Electromagnetic radiation from the sun, mostly at short wavelengths in the form of light, is able to pass through the atmosphere and is absorbed by Earth. Earth re-radiates some of this energy back toward space as heat, which is long-wave radiation. Most of the heat is able to pass through the atmosphere and escape into space, but some is absorbed by the atmosphere and then re-emitted back to Earth.
11. **Slide 19 (b)**: now explain the diagram on the right. [Click to make the graphic appear.] This is the enhanced greenhouse effect, which is caused by increased greenhouse gases in our atmosphere. As more greenhouse gases are released into the atmosphere, more of the re-radiated heat from Earth is re-emitted back to Earth instead of escaping to space. This is causing the average global temperature to increase.
12. **Slide 20**: this pie chart shows the percentage of each of the greenhouse gases that humans emit through our activities. Carbon dioxide accounts for 81% of the greenhouse gases that we release.
13. **Slide 21**: because carbon dioxide is the greenhouse gas that we emit in the largest amount, let's take a look at how we release it. Humans emit carbon dioxide mostly through fossil fuel combustion, i.e. the burning of coal, natural gas, and oil, for the production of electricity and transportation. Many industrial processes rely on fossil fuel combustion as well, and the production of mineral products, such as cement, the production of metals, and the production of chemicals can all result in carbon dioxide emissions.
14. **Slide 22**: remember the phenomenon that we are investigating today. Let's conduct an experiment to model the effect of carbon dioxide on Earth's temperature.
15. **Slide 23**: stop the presentation here, and display this slide while students are conducting the Towel and Towel + Space Blanket Trials.

Experimental Trials

16. Ask students to read the current temperature of their thermometers and tell you whether it has increased, decreased, or stayed the same since they clipped it to their clothing. The temperature should

have increased initially and then mostly stabilized.

17. Once the temperature has stabilized, direct each team's data recorder to record the temperature in the lap row of the Temperature column. The data recorder is the team member who is responsible for writing down all of the data during the experiment, but all students must complete the data table as well.
18. For groups conducting the Towel Trial, instruct the materials manager to give the towel to the test subject. For groups conducing the Towel + Space Blanket Trial, ask the materials manager to give the towel and then the space blanket rectangle to the test subject. For both trial groups, the test subject lays the towel over the thermometer and across their lap so that its long side is perpendicular to their thighs. In only the Towel + Space Blanket Trial groups, the test subject will then place the space blanket rectangle on top. Both should be oriented so that the long side is perpendicular to their thighs. If possible, the test subject should tuck the ends of the towel/blanket under their legs; if they will not tuck under, just ensure that they are covering the thermometer. See slide 23 for example photos of both trial setups.
19. As soon as the towel and space blanket (if applicable) are in place, instruct the timer to press the start button on the stopwatch.
20. Explain to the timer that for each minute that passes, they are to call out the time to the data recorder.
21. Explain to the data recorder that when the timer calls out the time, they are to read the temperature on the thermometer and record it in the corresponding row of the table.
22. Tell students to stop recording after 5 minutes.
23. The test subject can remove the towel, space blanket (if applicable), and thermometer.
24. Instruct students to answer question 3 in which they will calculate the difference in their group's ending and beginning trial temperatures.
25. Ask students to report the temperature difference from their trial to the class. Have students record their differences in the table on the board, or they can call them out to you while you write them on the board. Students must then record them in their "Whole Class" table on their handout and calculate the mean temperature difference for the Towel Trial and the Towel + Space Blanket Trial.
26. **Slide 24**: quickly review the left and right sides of the diagram, explaining the natural greenhouse effect and the enhanced greenhouse effect.
27. **Slide 25**: the experiment that you conducted was a model of the natural greenhouse effect and the enhanced greenhouse effect.
    a. Which item in the experiment modeled the earth? How it is like the earth? [Click to make the answer appear: the student's lap modeled the earth because it emits heat.]
    b. Which item in the experiment modeled the atmosphere? How it is like the atmosphere? [Click to make the answer appear: the towel modeled the atmosphere because the towel absorbed some of the heat and re-emitted it back toward the lap, effectively trapping it and keeping the lap warmer.]
    c. Which item in the experiment modeled additional carbon dioxide and other greenhouse gases? How it is like additional greenhouse gases? [Click to make the answer appear: the space blanket because, once it was added, more of the heat from the lap was re-emitted back to the lap instead of escaping into the room.]
28. Have students answer the Results and Conclusion questions 4-5.

WRAP UP AND FEEDBACK LOOP

1. **Slide 26**: Scientists have recorded data on Earth temperatures since 1880. NASA scientists created this graph showing the temperature anomalies every year. Scientists calculate temperature anomalies by comparing each year to average temperatures during a base period from 1951-1980. Temperature anomalies below zero are lower than the average temperatures during the base period, and those above zero are higher. Ask students to describe the trend of this graph [answer: temperature is increasing].
2. **Slide 27**: this graph shows both carbon dioxide, which is represented by the black line, and global temperature, which is represented by the blue and red bars (below and above the long-term average). Can you see a relationship? [answer: as carbon dioxide increases, global temperature increases.]
3. **Slide 28**: now we can add another piece to our positive feedback loop. Increasing carbon dioxide leads to increasing temperature.
4. **Slide 29**: over 70% of Earth is covered in oceans, so when thinking about the effects of increasing temperature, we must consider how it affects the oceans.
    a. Thermal expansion happens when thermal energy is transferred to water. Water molecules move faster when they are warmer, and they take up more space, causing the volume of water to increase.
    b. On average, glaciers have been losing mass since at least the 1970s, and there is a large photographic library of evidence, like the photos shown here from Plateau Glacier in Alaska, which has all but disappeared. Where does this melted water go? [answer: water from melting

ice sheets and glaciers flows into the ocean, which results in rising sea level.]

5. **Slide 30**: now we can add another piece of our positive feedback loop. Increasing temperature leads to melting ice and thermal expansion.
6. **Slide 31**: let's consider how melting ice and thermal expansion affect sea level with an example. Which city is this?
   a. [Click to make the city information appear.] This is Honolulu, Hawai'i. It is the state capital and largest city in Hawai'i and is estimated to have more than 350,000 people. The metro area of Honolulu, which includes the city and county of Honolulu, contains more than 950,000 people.
7. **Slide 32**: scientists at NOAA have created an online tool called the Sea Level Rise Viewer, which uses data on historic sea level rise and geographic information. Models were developed by scientists at the US Global Change Research Program to predict future sea level under different scenarios; NOAA used the models to create this tool which displays the impacts of sea level rise in the United States.
   a. We will examine Honolulu because it is an important US city that is particularly vulnerable to the effects of sea level rise.
   b. This first image shows Honolulu at current sea level.
8. **Slides 33-36**: we will move through these next few images quickly. Look for differences in where the water is as we move through the projected sea level rise in Honolulu every 20 years. [Flip through the slides quickly, narrating with as much of the information below as you have time to include.]
   a. **Slide 33** shows Honolulu just after the year 2020. In the circled area by the lagoon, flooding is going to start to occur in areas with buildings.
   b. **Slide 34** shows just after the year 2040 with a 2-foot projected sea level rise. In the same area by the lagoon, you can see that flooding is projected to move farther into these areas with buildings.
   c. **Slide 35** shows just after the year 2060 with a 4-foot projected sea level rise. A great deal of the populated areas with buildings along the coast are projected to experience flooding.
   d. **Slide 36** shows even more projected flooding all throughout the city, just after the year 2080 with a 6-foot projected sea level rise.
9. **Slide 37**: this the projected sea level at the turn of the century (the year 2100). Large portions of Honolulu are projected to be underwater. Imagine how many people will be affected and the impacts it will have on the city.
   a. In the state of Hawaii, it is estimated that over the next 30-70 years, approximately 6,500 structures and almost 20,000 people will be exposed to chronic flooding, and $19 billion in economic loss will result.
10. **Slide 38**: now we can add another piece to our positive feedback loop. Melting ice and thermal expansion lead to sea level rise.
11. **Slide 39**: what about coastal areas that are not heavily populated by people? Coastal wetlands, such as tidal marshes and mangroves, take up over 100 teragrams (Tg, i.e. trillion grams) of carbon globally per year. They take up more carbon per unit area than any natural system and are an important carbon reservoir. Coastal wetlands take up carbon so effectively by converting it to plant biomass more quickly than other ecosystems, trapping carbon in their sediments, and delaying the decomposition of organic matter, which releases carbon dioxide (Witman, 2017). Sea level rise threatens to disrupt this important ecosystem service of coastal wetlands. If they are destroyed by sea level rise, they will no longer be able to take up carbon.
12. **Slide 40**: let's think about how it all ties together. Carbon dioxide, global warming, sea level rise, and coastal wetland destruction are all part of a positive feedback loop. Remember, in a positive feedback loop, the increase of one factor causes the increase of another and so on. Positive feedback loops are destabilizing. The word stable means that something isn't changing. Positive feedback loops move a system away from its original state; they lead to change. In this case, the positive feedback leads to more warming. Remember, the effects of a positive feedback loop are not necessarily positive. Don't let the name fool you. Sometimes, such as in this example, the increases at each step of the loop lead to a negative impact on the system.
   a. As we saw in the NOAA IADV activity (or if not done, NOAA Mauna Loa atmospheric carbon dioxide graph), atmospheric carbon dioxide is increasing.
   b. [Click to make the text and graphic appear.] As we saw in the greenhouse effect experiment, increasing carbon dioxide leads to increasing global temperature.
   c. [Click to make the text and graphic appear.] Increasing global temperature leads to melting ice sheets and glaciers and thermal expansion.
   d. [Click to make the text and graphic appear.] Melting ice and thermal expansion lead to sea level rise.
   e. [Click to make the text and graphic appear.] Sea level rise leads to destruction of coastal wetlands.
   f. [Click to make the text and graphic appear.] Because

coastal wetlands are facing destruction and cannot continue to take up carbon as they are destroyed, carbon dioxide continues to increase even more.

g. This intensifies the original impact, which was increased atmospheric carbon dioxide, and the positive feedback loop continues.

13. **Slide 41**: remember, we conducted these activities today to examine this phenomenon. Carbon dioxide in the atmosphere is affecting temperatures on Earth, resulting in several positive feedback loops.
14. Now think about the evidence that you have gathered to understand and explain this phenomenon, and answer questions 6-8.
15. Time permitting, ask students to share their answers to questions 6-8, and discuss them.
16. **Slide 42**: what can we do? Technologies already exist to mitigate climate change (Pacala and Socolow, 2004). Mitigation means to reduce the impact to the environment or another resource. Mitigation can be used to reduce the amount of greenhouse gases released into the atmosphere. Strategies include using more electric cars, driving less, increased efficiency of power plants, increased use of biofuels, and increasing efficiency of building systems, such as heating and cooling, water heating, lighting, and refrigeration. Do you know of others?

EXTENSION

1. In small groups, have students conduct research on other climate feedback loops, choose a new feedback loop, develop a diagram and related questions, and ask the questions to fellow students.

ADDITIONAL RESOURCES

Environmental Protection Agency (EPA). Climate Change Indicators. Updated Aug. 2016. Web. Accessed 04 Mar. 2019. <https://www.epa.gov/climate-indicators/climate-change-indicators-glaciers>.

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Hawai'i Climate Change Mitigation and Adaptation Commission (HCCMAC). 2017. Hawai'i Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawai'i Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai'i Department of Land and Natural Resources Contract No: 64064.

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Pacala, S. and R. Socolow. 2004. Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. Science 305: 968-972.

Witman, S. 2017. Coastal wetlands effectively sequester "blue carbon," Eos, 98. Web. Accessed 19 Feb. 2020. <https://eos.org/research-spotlights/coastal-wetlands-effectively-sequester-blue-carbon>.