Lesson 3: Explaining Connections Between Patterns

Tab 1: Overview

Students examine the relationship between atmospheric CO_2 and atmospheric temperature rise.

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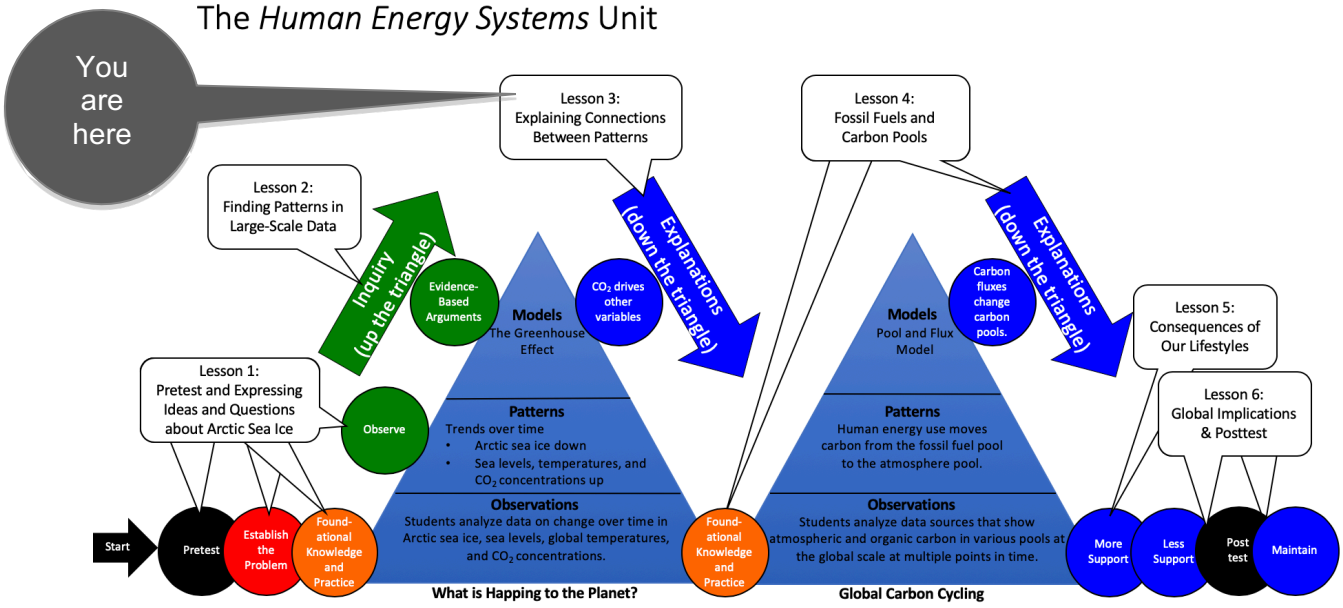
Guiding Question

How are changes in global temperatures, sea levels, Arctic sea ice, and atmospheric CO_2 connected?

Activities in this Lesson

- Activity 3.1 Millions of Flasks of Air (25 minutes)
- Activity 3.2 The Greenhouse Effect Reading & Simulation (20 minutes)
- Activity 3.3 Relationships between Earth Systems (40 minutes)

Unit Map



Tab 2: Learning Goals

Target Performances

Activity	*Target Performance*
Lesson 3 – Explaining Connections between Patterns (students as explainers)	
Activity 3.1: Millions of Flasks of Air (25 min)	Students explain why Charles David Keeling went to Hawaii to collect data on atmospheric CO_2 concentrations and how he made his measurements.
Activity 3.2: The Greenhouse Effect (20 min)	Students use a computer simulation to explain how carbon dioxide absorbs visible light and emits infrared radiation—the Greenhouse Effect.

Activity	*Target Performance*
Activity 3.3: Explaining Relationships Between Earth Systems (40 min)	Students use the Greenhouse Effect to explain how atmospheric CO_2 concentration is the driver that causes changes in other Earth systems.

NGSS Performance Expectations

High School

- Ecosystems: Interactions, Energy, and Dynamics. HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.
- Earth's Systems. HS-ESS2-2. Analyze geoscience data to make the claim that a change to Earth's surface can create feedbacks that cause changes to other Earth systems.
- Weather and Climate. HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
- Earth and Human Activity. HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.
- Earth and Human Activity. HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

Middle School

- Waves and Electronic Radiation. MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
- Earth's Systems. MS-ESS2-1. Develop a model to describe the cycling of the Earth's materials and the flow of energy that drives this process.
- Human Impacts. MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capital consumption of natural resources impact Earth's systems.
- Earth and Human Activity. MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.

Tab 3: Background Information

Three-dimensional Learning Progression (accordion)

Lesson 3 focuses on students examining key foundational knowledge about how CO_2 interacts with energy in the atmosphere. In order to understand the longer chain of events that leads to Arctic sea ice decrease and sea level rise, students must first understand that (a) we have evidence that CO_2 is increasing in the atmosphere, and that (b) greenhouse gases interact with long-wave radiation coming from the Earth's surface in ways that increase temperatures.

Lesson 3 focuses on how CO_2 and other greenhouse gases affect the Earth's temperature. Your students may be familiar with the metaphor that greenhouse gases act like a blanket to keep the Earth warm. That's not a terrible metaphor, in that both blankets and greenhouse gases slow down heat transfer, but it has significant limitations. The mechanisms

are different: blankets reduce heat transfer by reducing convection, while greenhouse gases reduce heat transfer by reducing radiation.

More importantly, a key goal for the *Human Energy Systems* unit is to help students explain changes by tracing pools and fluxes of energy and matter. Lessons 4 and 5 focus on matter; this lesson focuses on energy. Students need to understand that the Earth's temperature depends on the balance between two different energy fluxes:

- The sun's radiation coming in (mostly in the form of visible light)
- Infrared radiation going out (mostly in the form of infrared light)

During a typical day there is more radiation coming in, so the Earth's pool of thermal energy gets larger and the temperature rises. During a typical night there is more radiation going out, so the Earth's pool of thermal energy gets smaller and the temperature falls.

Greenhouse gases have their effects because they absorb infrared but not visible light, so they slow down only the outgoing energy flux, causing the Earth's temperature to gradually rise.

In Lessons 4 and 5 students will explain carbon pools and fluxes in multiple Earth Systems. The goal of this lesson is to helps students identify the causal relationship between atmospheric CO_2 concentrations and temperature (the Greenhouse Effect), and to establish the problem for a deeper study of the Keeling Curve.

Key Ideas and Practices for Each Activity (accordion)

In Activity 3.1 students learn about a scientist named Charles David Keeling by reading a short story and listening to a radio broadcast. These stories explain how Keeling's research alerted the global community to the fact that atmospheric CO_2 is increasing, and what work lead to the discovery of this important information. Previously, students used the graphs but did not yet know how the data were collected.

In Activity 3.2, students examine the Greenhouse Effect. This gives them the first piece of evidence they need to eventually explain that increasing atmospheric CO_2 is the driving factor among the multiple Earth systems they examined in the previous lesson. This causal chain of events includes the Greenhouse Effect, or the interaction between greenhouse gases and long-wave radiation coming from Earth that traps heat in the atmosphere. Upon completing the reading, students will utilize a simulation to investigate the interactions between different atmospheric gases and different forms of radiation.

Note that the analogy between the atmospheric Greenhouse Effect and actual greenhouses (or the closed car that is used as an analogy in the reading) is not perfect. Greenhouse gases are like glass in that they absorb infrared radiation, but unlike greenhouse gases, glass also blocks heat loss by convection.

In Activity 3.3, students use a concept map to document their ideas about the relationships between different Earth systems at this stage in the unit. With their new knowledge of the greenhouse effect, this should begin to resemble a scientific explanation for the relationship between increases in atmospheric CO_2 and temperature rise.

Content Boundaries and Extensions (accordion)

This lesson focuses on how greenhouse gases affect energy fluxes, and how that makes CO_2 concentrations the driver of other changes in Earth systems. Students may be interested in how molecular vibrations lead to absorption of infrared radiation (discussed briefly in The Greenhouse Effect Reading, but this is not a primary focus for this lesson.

Activity 3.1: Millions of Flasks of Air (25 min)

Tab 1: Overview and Preparation

Target Student Performance

Students explain why Charles David Keeling went to Hawaii to collect data on atmospheric CO_2 concentrations and how he made his measurements.

Resources Provided

- 3.1 Millions of Flasks of Air Reading (1 per student)
- (Optional) "Climate Change is Clear Atop Mauna Loa" a 12-minute radio story about climate change: http://www.npr.org/templates/story/story.php?storyId=9885767

Recurring Resources

- Questions, Connections, Questions Student Reading Strategy

Setup

Print one copy of 3.1 Millions of Flasks of Air Reading per student.

Tab 2: Directions (accordion for individual steps in directions)

1. Introduce students to the most important molecule of the unit: carbon dioxide!

Have students recall the Keeling Curve from the previous activity. Post the question: "How do scientists know CO_2 is increasing in the atmosphere?" Tell them that in this activity they will read a story that explains the research behind this scientific knowledge.

2. Introduce the reading.

Tell students that one of the reasons we know that carbon dioxide is increasing in the atmosphere is because of a scientist named Charles David Keeling and his research. The reading during this activity will introduce us to who he was and why his research was so important.

3. Have students "read a little, talk a little."

Divide students into pairs. Give each student a copy of the 3.1 Millions of Flasks of Air Reading. Have students read 3.1 Millions of Flasks of Air Reading using the Questions, Connections, Questions Student Reading Strategy. See the Questions, Connections, Questions Reading Strategy Educator Resource document for information about how to engage students with this strategy.

4. Discuss the reading as a class.

After students have had a chance to read the text, ask them for any reflections on the reading. Consider using these questions to spark the discussion:

- What did Charles Keeling discover?
- Why is this important?
- What did you learn from this reading that you didn't know before?
- If you could ask Charles Keeling a question about his research, what would you ask?
- What parts of the reading were hard to understand?

5. (Optional) Summarize the reading's main ideas.

After the class discussion, ask students to share what they think are the main ideas from the reading. Record their ideas on a piece of large poster paper so the students can revisit the main ideas throughout the unit. Consider making a vocabulary wall with words that students needed help understanding.

6. Make connections to previous lessons.

Ask students to recall what they already know about the "Keeling Curve" from the previous lessons. Have them recall what they remember about this graph. Hint: the members of the expert group from Lesson 2 that examined the Keeling Curve may have a better memory than other students.

7. (Optional) Listen to a radio story about the Keeling Curve.

To reiterate the main ideas in the reading, listen to this 12-minute radio story about Charles Keeling and his research. This story provides an audio recording of the "shhhhhttttthhhhleep" sound discussed in the handout. When listening to the story:

- Ask students to identify similarities in the main ideas of the radio story and the main ideas from the handout.
- Ask students to identify new information in the radio story that was not in the handout.
- If you recorded the students' main ideas on a large piece of poster paper, revise this poster with the new ideas from the radio story.

Tab 3: Assessment

Tips

- You may want to display an image of the Keeling Curve on the overhead projector or in the classroom during this Activity.
- Remind students that the data they are reading about in the handout and listening to in the story is the same data they examined in the previous activity: The Keeling Curve.

Tab 4: Differentiation & Extending the Learning

Differentiation (Accordion)

- Strategic groups with strong speakers.
- Allow students to have small group discussions with the questions in step 4 before sharing to the whole class.

Modifications (Accordion)

Have students read text as individuals and then ask their partners questions about what they read.

Extending the Learning (Accordion)

Ask students to listen to or read other popular media about Charles Keeling. Tell students that the Keeling Curve graph is an important graph that scientists use to understand carbon dioxide concentrations in the atmosphere. But why is it so important? We will learn the answer to this question throughout the unit.

Activity 3.2: The Greenhouse Effect Reading & Simulation (20 min)

Tab 1: Overview and Preparation

Target Student Performance

Students use a computer simulation to explain how carbon dioxide absorbs visible light and emits infrared radiation—the Greenhouse Effect.

Resources Provided

- 3.2 The Greenhouse Effect Reading
- 3.2 The Greenhouse Effect Simulation Worksheet
- 3.2 Grading The Greenhouse Effect Simulation Worksheet
- Greenhouse Effect PhET simulation: https://phet.colorado.edu/en/simulation/greenhouse
- Optional data ("Global Warming's Six Americas") of attitudes toward climate change: https://www.americanprogress.org/issues/green/reports/2009/05/19/6042/global-warmings-six-americas/

Recurring Resources

- Questions, Connections, Questions Student Reading Strategy

Setup

Prepare enough copies of the 3.2 The Greenhouse Effect Reading for each student to have one. Prepare enough copies of the 3.2 The Greenhouse Effect Simulation Worksheet for each pair or team of students. Download the PhET Simulation on the computers used by students by going to this link: https://phet.colorado.edu/en/simulation/greenhouse

Note that you may need to modify the security preferences on some computers in order to open the simulation.

Tab 2: Directions (accordion for individual steps in directions)

1. Introduce the activity.

Tell students we spend a lot of time discussing the Keeling Curve in this unit, but why is this important? Ask students for their initial ideas: "*Does anyone have an idea about why scientists might care so much about the Keeling curve?"* It is important for understanding how increasing CO_2 in the air is connected to global climate change.

2. Introduce the reading.

Tell the students that the scientific community is concerned about the rising concentrations of CO_2 and what this means for the global atmospheric and oceanic temperatures, sea level, and how this might change the climate.

To understand why scientists are concerned, we have to talk about two things: the greenhouse fossil fuels.

3. Have students complete the reading in small groups.

Give each student a copy of the 3.2 The Greenhouse Effect Reading. Before they complete the reading in small groups, inform students that they will be using this reading to better understand the greenhouse effect.

Instruct students to be prepared to explain the greenhouse effect as a group once they have completed the reading, and that they should work together as a team to come up with an explanation.

Have students read 3.2 The Greenhouse Effect Reading using the Questions, Connections, Questions Student Reading Strategy. See the Questions, Connections, Questions Reading Strategy Educator Resource document for information about how to engage students with this strategy.

- Once all student teams have had sufficient time to complete this activity, work as a class to explain mechanism of the greenhouse effect. Stress that the greenhouse effect is a naturally occurring phenomenon that keeps our planet warm and allows us to survive. This is different from global warming and climate change, which are caused by humans.[1] Although the greenhouse effect is naturally occurring, the human-caused amplification of the greenhouse effect is not "natural." Be sure to clarify the central idea that a greenhouse gas allows light energy (photons) to pass through the atmosphere but slows the loss of infrared radiation by absorbing and re-emitting some of that radiation back towards the surface of the earth.

Teacher Note: "Light energy" from the sun refers to the sun's electromagnetic radiation, which includes ultraviolet radiation (among others). Ultraviolet radiation is shortwave and can pass through the atmospheric particles without getting trapped.

- Explain that Light energy from the sun interacts with the earth's surface and is returned to the atmosphere in the form of infrared, or long-wave radiation. Some of this energy is trapped by greenhouse gases, which keeps the earth warm. Some goes back to space. When greenhouse gases trap infrared radiation, the planet stays warm.

Teacher Note: There are other greenhouse gases. In this unit, we focus mainly on carbon dioxide because this is the most important greenhouse gas and a product of fossil fuel combustion. Other greenhouse gases include methane, nitrous oxides, fluorinated gases, water, and others.

4. Have students complete 3.2 The Greenhouse Effect Simulation Worksheet.

For this activity, students will need access to a computer. It is advisable that you download the PhET simulation in advance. To do so, follow this link and select download: https://phet.colorado.edu/en/simulation/greenhouse (Depending on the settings on students' computers, they may need to go to System Preferences to give permission for the computer to run the simulation software.)

- Give each student a copy of the 3.2 The Greenhouse Effect Simulation Worksheet. Have them use the printed instructions to complete the activity (you may prefer to provide a

[1] It is possible that some students will challenge the claim that climate change is caused by humans by pointing to natural cycles in the Earth's history, claiming that the current highs are due to this natural cycle. Try to help them understand that part of what they are saying is true: Earth *does* have a history of CO_2 and temperature fluctuations. However, this does not contradict the scientific evidence for anthropogenic climate change: the *current* increase of CO_2 and other greenhouse gases in the atmosphere is a result of human use of fossil fuels and deforestation, which has caused the global temperature to rise 0.8° C (1.4° F) since 1900. That might not sound like a lot, but that is almost 10x faster than any other naturally occurring warming period in Earth's history.

sample demonstration of how the program works using an overhead projector). Instruct students to complete the worksheet as they are using the simulation.

5. Discuss the Worksheet Questions.

After students have had sufficient time to complete the activity, have them prepare to address the three main questions as a team for the class.

Allow students to take a few minutes to review these questions as a group and then randomly select a couple of student teams to provide their response to each of the following:

1. How do different gases in the atmosphere interact with light?
2. How do gases in the atmosphere affect the Earth's temperature?
3. Why is the Keeling Curve important?

6. Discuss how fossil fuels affect the earth's temperature.

Explain that combustion of fossil fuels releases carbon dioxide, which is a primary greenhouse gas. Ask students if they can think of examples of ways we use these fossil fuels in our daily lives.

7. (Optional). Have students review data about attitudes toward climate change and dig deeper into the greenhouse effect.

Review the Global Warming's Six Americas data with students focusing on the graphs and figures. Discuss where students fall: Alarmed, Concerned, Cautious, Disengaged, Doubtful, or Dismissive. This discussion will allow you to assess the range of *attitudes* towards climate change in your classroom at the beginning of the unit.

You can also use the resources in Extending the Learning below (included in the Digging Deeper section of the reading) to help students develop a deeper understanding of the greenhouse effect.

8. Have students complete an exit ticket.

- Conclusions: How does carbon dioxide interact with visible light and infrared radiation?
- Predictions: How do you think that carbon dioxide affects the Earth's temperature?
- On a sheet of paper or a sticky note, have students individually answer the exit ticket questions. Depending on time, you may have students answer both questions, assign students to answer a particular question, or let students choose one question to answer. Collect and review the answers.
- The conclusions question will provide you with information about what your students are taking away from the activity. Student answers to the conclusions question can be used on the Driving Question Board (if you are using one). The predictions question allows students to begin thinking about the next activity and allows you to assess their current ideas as you prepare for the next activity. Student answers to the predictions question can be used as a lead into the next activity.

Tab 3: Assessment

Listen for students' initial ideas about how atmospheric CO_2 and temperature are connected. Do they see a causal relationship? At this point, they may have many unanswered questions about how increasing greenhouse gases in the atmosphere lead to climate change. However, at the end of this activity, they should have a good understanding of how increasing greenhouse gases in the atmosphere lead to warmer temperatures as a result of the greenhouse effect. If

the students are still having trouble making this connection, you may want to show the students different models of the greenhouse effect that help explain this phenomenon.

Tips

If you choose to have students take the optional survey in step 7, you may want to ask students to turn in their results anonymously. This will give you an assessment of the range of attitudes in your classroom but will not stigmatize individuals based on their profile results.

Tab 4: Differentiation & Extending the Learning

Differentiation (Accordion)

- Allow students to work in pairs or groups to complete the PhET simulation.
- Go through the PhET simulation as a whole class, completing the worksheet together.
- Provide sentence stems for students to complete the questions on the worksheet.

Modifications (Accordion)

Ask students to share with the class their ideas about why increasing levels of carbon dioxide in the atmosphere is related to additional Earth systems other than temperature (e.g., sea level rise, arctic sea ice melt).

Extending the Learning (Accordion)

Encourage students to watch for references to climate change or global warming in the newspapers, magazines, and other media. Ask them to be "critical consumers," and to consider the sources of the information. Does the author/speaker provide evidence to support the claim? What evidence does the author/speaker provide?

Advanced students may find it interesting to research differences on the Earth in the past when carbon dioxide levels and temperature were at their highest. What animals and plants lived on the Earth then? What was the climate like?

Some students may have questions about how infrared radiation interacts with greenhouse gas molecules to produce heat. Although we do not go into this amount of detail in this unit, students may find these resources helpful:

- This website has an animated GIF that models infrared radiation and molecule vibration. It uses "absorption-emission-absorption" and vibrations to explain this phenomenon. https://scied.ucar.edu/carbon-dioxide-absorbs-and-re-emits-infrared-radiation
- This website from the American Chemical Society explains the phenomenon in more advanced terms, including the Global Warming Potential for each greenhouse gas molecule: http://www.acs.org/content/acs/en/climatescience/greenhousegases/properties.html
- For more information about how this creates a feedback loop, see this website from the American Chemical Society: http://www.acs.org/content/acs/en/climatescience/atmosphericwarming/climatsensitivity.html
- This 10 minute video of Richard Feynman explaining "jiggling atoms" might be helpful for students trying to understand how radiation interacts with atoms to produce heat: https://www.youtube.com/watch?v=NsdCzujHqAk

Activity 3.3: Relationships between Earth Systems (40 min)

Tab 1: Overview and Preparation

Target Student Performance

Students use the Greenhouse Effect to explain how atmospheric CO_2 concentration is the driver that causes changes in other Earth systems.

Resources Provided

- 3.3 Explaining Relationships Between Earth Systems Worksheet
- 3.3 Grading the Explaining Relationships Between Earth Systems Worksheet

Recurring Resources

- Learning Tracking Tool for Human Energy Systems (1 per student)
- Assessing the Learning Tracking Tool for Human Energy Systems

Setup

Print one copy of 3.3 Explaining Relationships between Earth Systems Worksheet per student.

Tab 2: Directions (accordion for individual steps in directions)

1. Have students recall ideas about the relationship between CO_2 and temperature.

Remind students that in the previous activity they examined the mechanism called the "greenhouse effect." Ask volunteers to explain in their own words what the greenhouse effect is.

Use student ideas to construct a group explanation for the greenhouse effect.

Listen for and highlight key ideas: short-wave radiation entering Earth's atmosphere passes through greenhouse gasses (GHGs); long-wave radiation is emitted into the atmosphere after it interacts with the Earth's surface; long-wave radiation interacts with GHGs which causes an increase in temperature.

2. Revisit the four Earth systems.

Give each student one copy of 3.3 Explaining Relationships Between Earth Systems Worksheet.

Draw students' attention to the four phenomena on page 1 of the worksheet.

Ask the class for any ideas about how these four phenomena might be related.

Remind students that the scientific community is concerned about the rising concentrations of CO_2 and what this means for the global atmospheric / oceanic temperatures, and how this might change the climate (which relates to the extents of the Arctic ice and the sea levels). This activity will help students begin unpacking connections between these variables.

3. Have students complete the worksheet by drawing arrows to indicate relationships between the phenomena.

Give students 3-5 minutes to draw their arrows on the concept map on page 2 of the worksheet. When they have finished, ask them to compare their arrows with a neighbor and discuss differences.

Ask the pairs to raise their hands if their arrows and explanations matched their partners.

Ask the pair to raise their hands if their arrows and explanations differed from their partners. Ask them to explain how they differed.

4. Construct a group explanation for the relationship between Earth systems.

In a location where all students can see, replicate the four boxes on a white board or poster paper. Using the students' ideas as a starting place, ask them where the arrows should go, and which explanations go with each arrow. If students disagree, ask them to explain their ideas.

Point out to the students that the goal of this conversation is to build consensus around where the arrows and explanations go. At this point, they will have evidence that atmospheric CO_2 causes an increase in temperature. Have them use the other explanations presented in the worksheet to piece together their explanation.

Use the question "What is causing what?" as a guiding question during this group conversation.

5. Have students construct an individual written explanation for the relationships.

Tell students to use their own concept map (arrows and boxes) and the class concept map to construct a written explanation for the relationship between the four Earth systems.

Give students 5-10 minutes to construct a written explanation on their worksheet.

Remind students to use evidence (from what they know of the greenhouse effect and the explanations on the concept map) in their explanations.

6. Have students share their explanations in groups.

Divide students into groups of four. Tell them that they should compare their explanations in groups with the goal of reaching consensus. The question their explanations should be answering is "What is causing these systems to change?"

Use this conversation as formative assessment to determine if your students are able to reach consensus about their explanations.

7. Have a discussion to introduce the Learning Tracking Tool for this activity.

- Pass out a Learning Tracking Tool for Human Energy Systems to each student.
- Explain that students will add to the tool after activities to keep track of what they have figured out that will help them to answer the unit driving question.
- Discuss goals for this lesson.
- Have students write the activity name in the first column, "Questions for this Lesson."
- Have a class discussion about what students figured out during the activity that will help them in answering the lesson driving questions:
  - What causes the annual cycle: CO_2 concentrations in Hawaii to go down every summer and up every winter?
  - What causes the long-term trend: CO_2 concentrations to go up every year?
  - How can we predict what will happen to CO_2 concentrations in the future?
- When you come to consensus as a class, have students record the answer in the second column of the tool.

- Have a class discussion about what students are wondering now that will help them move towards answering the unit driving question. Have students record the questions in the third column of the tool.
- Have students keep their Learning Tracking Tool for future activities.
- Example Learning Tracking Tool

Activity	What We Figured Out	What We are Asking Now
3.3 Explaining Relationships Between Earth Systems	*CO_2 is the driver: Changes in atmospheric CO_2 cause changes in Arctic sea ice, global temperature, and sea level.*	*What causes changes in CO_2 concentrations and how can we predict those changes?*

Tab 3: Assessment

Use the 3.3 Grading the Explaining Relationships between Earth Systems Worksheet as a guide during the small and large group discussions in this activity. Because the goal of the conversation is consensus, try to encourage the class to discuss any ideas that diverge from the scientific explanation. By the time they have finished constructing their written explanations, they should be able to point to increasing CO2 levels as the driver of all Earth systems on the worksheet, which causes increased global temperatures, which in turn causes sea level rise and arctic ice melt.

Tips

Have students sit in small groups of 3-4 during the introduction to the worksheet so that they have an opportunity to discuss possible relationships between the graphs before sharing out with the class. From the first group, you can have one person from the group report out their thoughts. The next (and remainder of the) groups can either agree or share other ideas they have about relationships between the graphs. If conflicting ideas arise, have students talk to each other to evaluate the differences – ideally, they should be able to reach consensus.

Tab 4: Differentiation & Extending the Learning

Differentiation (Accordion)

Modifications (Accordion)

Extending the Learning (Accordion)

From the worksheet, students can research and list other evidence that supports the relationships they identified between the four graphs.