Lesson 6: Global Implications & Posttest

Tab 1: Overview

Students consider the impacts that rising carbon dioxide levels have on the Earth's systems, discuss uncertainty in climate models and predictions, and consider the future of Earth's systems given different CO_2 emissions scenarios.

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Guiding Question

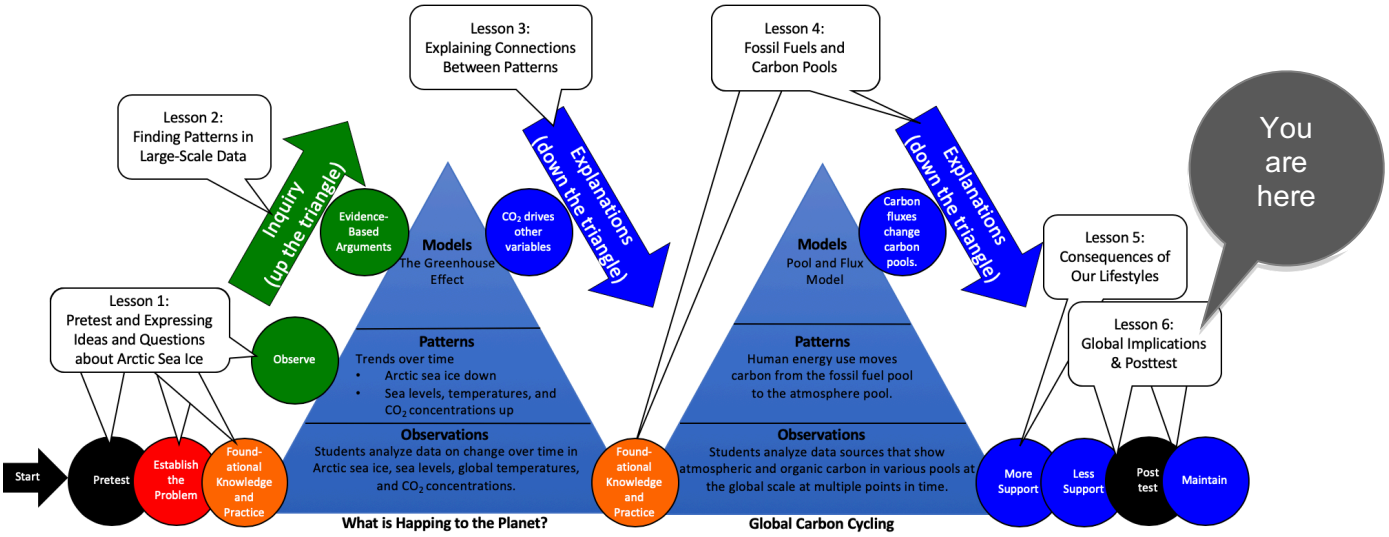
What does increasing CO_2 in the atmosphere mean for the future of the planet?

Activities in this Lesson

- Activity 6.1: Using Models to Predict Future Conditions (50 min)
- Activity 6.2: How Our Decisions Affect Earth's Future (30 min)
- Activity 6.3: Human Energy Systems Unit Posttest (20 min)

Unit Map

The *Human Energy Systems* Unit



Tab 2: Learning Goals

Target Performances

Activity	*Target Performance*
Lesson 6 – Global Implications and Posttest (students as explainers and predictors)	
Activity 6.1 Using Models to Predict Future Conditions (50 min)	Students use the online Very, Very Simple Climate Model to make predictions about future atmospheric CO_2 concentrations and global temperatures based on CO_2 emissions scenarios.

Activity	*Target Performance*
Activity 6.2 How Our Decisions Affect Earth's Future (30 min)	Students use graphs of projections from computer models to consider the impacts of increasing atmospheric CO_2 on Earth's systems and on living things.
Activity 6.3: Human Energy Systems Unit Posttest (20 min)	Students show their initial proficiencies for the overall unit goals: 1. Questioning, investigating, and explaining how the Earth's climate is changing 2. Explaining and predicting how carbon cycles and energy flows in 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 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.
- Ecosystems: Interactions, Energy, and Dynamics. HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
- Earth's Systems. 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.
- 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.

Middle School

- 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-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
- 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)

In Lesson 4 students studied global CO_2 fluxes changed atmospheric CO_2 concentrations, including the key role of the human-caused flux from burning fossil fuels. In Lesson 5 the studied human technological systems and activities and how they contribute to the unbalanced fossil fuel flux. In Lesson 6, they return to the global scale, considering how this unbalanced flux affects other aspects of Earth systems, such global temperatures, sea level, and Arctic sea ice. They use computer models to map out different scenarios for the future,

studying how the future of the planet will depend on humans' activities and decisions. Our goal is to help students see how those models are grounded in the scientific models and principles that they have studied, and to appreciate both the power and the limits of those models.

Key Ideas and Practices for Each Activity (accordion)

Activity 6.1 helps students examine how to use data from large-scale data sets to make predictions about what will happen in the future. This activity aims to help students distinguish between data sets that have predictable short-term variation (like the Keeling Curve) and data sets that have unpredictable (random or stochastic) short-term variation (like Arctic sea ice, global temperature, and sea level rise). We can use the stable seasonal cycle in the Keeling Curve to make predictions about CO_2 levels in the future months, years, and long term. This is because the short-term variation is due to a predictable flux of carbon atoms between the atmosphere and the biomass as a result of photosynthesis and cellular respiration. The long-term trend, which is a result of fossil fuel consumption, can be used to make predictions further into the future. Other phenomena such as Arctic Sea ice extent, global temperatures, and sea level have much more random variation that affect their short-term patterns and make them less useful for making precise predictions about the next few years. However, we can use the long-term trends in these data to make predictions about overall patterns in the future.

Activity 6.2 uses a very simple climate model to make predictions about future atmospheric CO_2 concentrations and global temperatures. Using this model students learn that even if CO_2 emissions remain constant or begin to decrease, atmospheric CO_2 (and therefore global temperatures) will continue to rise over the next century.

Activity 6.3 helps students begin to think about how our decisions affect Earth's future. This activity builds on the simple climate model in Activity 2 to show how scientists use models to predict what Earth's systems might look like in the future based on various emissions scenarios. These models operate with a degree of uncertainty but are useful for examining how different emissions scenarios or mitigation strategies may affect Earth's systems. We want the students to understand that computer models are useful even if they cannot predict the future with 100% accuracy, and that long-term trends from the past are valuable pieces of evidence on which to base future projections. This lesson concludes with questions about how our actions affect Earth's future that you may wish to investigate further.

Activity 6.4 is a posttest, enabling you to monitor your students' progress in understanding patterns in Earth systems, including climate change and global carbon cycling.

Key Carbon-Transforming Processes: Combustion, Photosynthesis, Fossil Fuel Formation, Cellular Respiration

Content Boundaries and Extensions (accordion)

[This could be a place to note deliberately omitted details and simplifications, referring to the content simplifications document if necessary, as well as suggested extensions or additional readings (with more details in the Activity pages).]

Activity 6.1: Using Models to Predict Future Conditions (50 min)

Tab 1: Overview and Preparation

Target Student Performance

Students use the online Very, Very Simple Climate Model to make predictions about future atmospheric CO_2 concentrations and global temperatures based on CO_2 emissions scenarios.

Resources Provided

- 6.1 Using Models to Predict Future Conditions Worksheet (1 per student)
- 6.1 Grading Using Models to Predict Future Conditions Worksheet

Setup

Prepare a computer with a projector to display the model at http://scied.ucar.edu/simple-climate-model

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

1. Introduce the Very, Very Simple Climate model.

Use a projector to display the Very, Very Simple Climate model at http://scied.ucar.edu/simple-climate-model.

- Tell students that *in this model, average global temperature is determined entirely by the amount of CO_2 in the atmosphere and its effect on temperature (the greenhouse effect). The model is based on the simple mathematical relationship between atmospheric CO_2 concentration and average global temperature, which states that temperature rises about 3°C each time atmospheric CO_2 doubles.*
- Show students how to change the CO_2 emissions by moving the slider and demonstrate how to run the model by clicking "step forward" or "play" at the top.

2. Use the Worksheet to work through the first scenario.

Pass out the 6.1 Using Models to Predict Future Conditions Worksheet and read scenario #1 out loud to the class.

- Ask students to predict what will happen to atmospheric CO_2 concentrations and temperature if CO_2 emissions remain constant at 10 GtC/yr by drawing the corresponding lines on their graph for question 1.
- Have a few students to share their predictions and reasoning with the class. You may wish to have them draw their predictions on the board.
- After making predictions, students should run the simulation and answer questions 3-7 with a partner.
- Discuss the results of scenario #1 with the class. It is important that students see that even when CO_2 emissions stay constant, the concentration of atmospheric CO_2 continues to increase and thus temperature continues to increase. This is surprising for many students because they often fail to distinguish between emissions (the CO_2 flux) and atmospheric CO_2 (the pool).

3. Students complete scenario #2 on the worksheet.

- Read scenario #2 out loud to the class.

- Ask students to predict what will happen to atmospheric CO_2 concentrations and temperature if CO_2 emissions continue to increase as shown on the graph. They should draw lines for CO_2 concentration and temperature on the graph to show their predictions.
- Have a few students to share their predictions and reasoning with the class. You may wish to have them draw their predictions on the board.
- After making predictions students should run the simulation and answer questions 10-13 with a partner.
- Discuss the results of scenario #2 with the class. Students should see that increasing CO_2 emissions causes atmospheric CO_2 and global temperatures to increase at a faster rate and reach higher maximums by the end of the century than in scenario #1.

4. Students develop a strategy for limiting climate change using the model.

Read the directions to the "Limiting climate change" section of the worksheet aloud.

- Check to be sure that students are able to find the box "Show Warming Limit Targets" on the model in order to get the lines for the pre-industrial average temperature and 2°C recommended warming limit to appear on the graph.
- Remind students that drastic reductions in CO_2 emissions over a short period of time would be nearly impossible to accomplish given our current global society. In addition, remind students that the graph only shows predicted temperatures up to the year 2100, but that we wouldn't want the temperature to increase more than 2°C even after that. They should keep in mind that the goal is to get the temperature to begin to level off well before the end of the century.
- Have students complete question 14 with a partner. They should indicate their results on the graph and explain their scenario in words.

5. Students share their scenarios (emissions settings and results) with the class.

Ask a few students to share their strategies for limiting warming to 2°C. It is important that students realize that CO_2 emissions must decrease if we hope to keep global temperature increases below the 2°C recommended warming limit. Discuss as a class how feasible their settings were. Check to make sure that they realize that drastic short-term reductions in CO_2 emissions or future emissions that are near zero would be virtually impossible given our current reliance on fossil fuels for everyday activities.

6. Have students complete an exit ticket.

- Conclusions: How much will humans need to reduce CO_2 emissions to stabilize the Earth's climate?
- Predictions: What could we do to change CO_2 emissions?
- 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

Use students' responses to the questions on the worksheet to assess their understanding of the effect of CO_2 emissions on atmospheric CO_2 and global temperatures.

Tab 4: Differentiation & Extending the Learning

Differentiation (Accordion)

- Run the simulation and fill out the worksheet together as a class.

Modifications (Accordion)

Extending the Learning (Accordion)

Activity 6.2: How Our Decisions Affect Earth's Future (30 min)

Tab 1: Overview and Preparation

Target Student Performance

Students use graphs of projections from computer models to consider the impacts of increasing atmospheric CO_2 on Earth's systems and on living things.

Resources Provided

- 6.2 How Our Decisions Affect the Earth's Future PPT

Recurring Resources

- (Optional) Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half? (1 per student)
- (Optional) Assessing the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half?

Recurring Resources

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

Setup

Prepare a computer with a projector to display the presentation. Print one copy of Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half? per student if you are using it.

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

1. Use the instructional model to show students where they are in the course of the unit.

Show slide 2 of the 6.2 How Our Decisions Affect the Earth's Future PPT.

2. Review how carbon emissions are impacting global climate systems.

Tell students in this unit we have been examining how and why carbon emissions are increasing in our atmosphere. But what is that doing to Earth's systems?

- Open the 6.2 How Our Decisions Affect the Earth's Future PPT and display slide 3. Remind students of the systems they studied in Lesson 3 of this Unit.
- Use slide 4 to review how rising atmospheric CO_2 intensifies the greenhouse effect and increases global temperatures, which in turn lead to sea level rise and decreases in Arctic Sea ice.
- Use slide 5 to explain that if we could lower CO_2 emissions then we could also have an impact on global temperature rise, sea ice melt, and sea level rise.
- Use slide 6 to review what students learned from using the Simple Climate Model in Activity 6.2. (1) If CO_2 emissions stay constant at current levels (about 10 GtC/year) atmospheric CO_2 (and thus temperature) would continue to increase, and (2) we would have to significantly decrease CO_2 emissions in order to stop the upward trend of atmospheric CO_2.
- Use slide 7 to review the imbalance in carbon pools and introduce the driving question: What will happen to Earth's systems if we don't reduce carbon emissions?

3. Review the IPCC climate model graph from Activity 6.2 to discuss how our decisions affect future temperatures.

Ask: *How will our decisions about future CO_2 emissions affect global temperature?*

- Students should recognize that the blue lines represent global temperatures if we decrease CO_2 emissions and the red line indicates predicted temperatures if we continue to increase CO_2 emissions at the current rate.
- RCPs: representative concentration pathways
- Remember, that many scientists recommend that we not allow the climate to warm more than 2°C (which will require decreasing CO_2 emissions from current levels).
- Check to make sure that students understand that the blue lines represent scenarios in which people change their behaviors related to fossil fuel usage to substantially reduce CO2 emissions (drastic and quick reduction for RCP2.6 and more gradual but very substantial reduction for RCP4.5). The red line (RCP8.5) shows what would likely happen to global temperature if CO2 emissions continue to increase as they have in the past.
- Ask: *What do you think the shaded areas around each line represents?* Shaded areas represent uncertainty around the projections. Models about the future are based on long-term trends in the past and our current understanding of how Earth's systems interact with each other. Therefore, predictions have a certain level of uncertainty around them.
- Notice that the greatest uncertainty is around the highest emissions scenario. This is because scientists are less certain about how Earth's systems would respond to drastic increases in atmospheric CO_2 (e.g. how much CO2 would dissolve in the ocean and at what rate, how feedbacks such as decreased reflection of solar radiation from ice would speed up warming, etc.)

4. Discuss computer models for predictions about sea ice and sea level.

Use slide 9 to discuss the computer models for sea ice extent.

- Use slide 10 to discuss the computer models for sea level rise.
- Notice that even if CO_2 emissions are drastically reduced, models predict that sea ice will continue to decline, and sea level will continue to increase.
- The IPCC 5th Report states, "Sea level will continue to rise for centuries, even if GHG [greenhouse gas] concentrations are stabilized, with the amount of rise dependent on future GHG emissions."

5. Discuss how changes in Earth's systems affect humans and other living things and consider questions for extending the learning beyond the Human *Energy Systems Unit*.

Use slide 11 to explain: *The decisions that we make as individuals and as communities and nations that affect CO_2 emissions will determine future global temperatures, amount of sea ice, and sea level*. Ask: *What impacts would increase global temperatures and sea level and decreased sea ice have on us and on other living things?* Have students discuss this question with a partner and then share out their ideas.

- Use slide 12 to remind students that they have learned a lot about the causes of climate change in this unit but have only begun to scratch the surface of how it will affect humans and other living things and what we might choose to do mitigate climate change. These questions suggest ways that you may decide to extend the learning.

6. (Optional) Have students complete the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half? for the final time.

If you decided to use the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half?, have students complete it and share their ideas again. Have students discuss how their ideas have changed throughout the unit. See Assessing the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half? and Using Big Idea Probes for suggestions about how to use the Big Idea Probe.

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

Show Slide 13 of the 6.2 How Our Decisions Affect the Earth's Future PPT.

- Have students take out their Learning Tracking Tool from the previous lesson.
- Have students write the activity name in the first column, "6.2 How Our Decisions Affect the Earth's Future."
- 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
6.2 How Our Decisions Affect the Earth's Future	*Human actions that affect CO_2 emissions will determine the future of our climate.*	

Tab 3: Assessment

Listen for the students' ideas about uncertainty in the predictions for sea level rise, global temperature, and arctic sea ice. How do they explain uncertainty in climate models?

Tab 4: Differentiation & Extending the Learning

Differentiation (Accordion)

Modifications (Accordion)

Extending the Learning (Accordion)

The Human Energy Systems Unit provides a foundation for understanding how human activities are increasing atmospheric CO_2 and how that leads to increased temperatures and other effects (sea level rise and declining Arctic Sea ice). This unit has barely scratched the surface of many important questions that you may want to explore further. Below are some ideas:

- **Climate change mitigation:** What can we do to decrease CO_2 emissions and the amount of CO_2 already in the atmosphere?
- Resource: Mitigation of climate Change video (about 12 minutes): https://www.youtube.com/watch?v=gDcGz1iVm6U
- **Effects of climate change:** How will the effects of climate change affect humans and other living things?
- Students can research the effect of climate change on something that is personally interesting to them. Some examples include: extreme weather such as storms and droughts, agriculture and food production, changes in animal habitats and breeding seasons, spread of mosquito-borne illnesses (malaria, Dengue Fever, West Nile virus, and Zika Virus), ocean acidification, effects of sea level rise on coastal habitats or flooding of human cities.
- **Climate models:** How were the RCP scenarios developed and how do scientists use them?
- Resource: The Beginner' Guide to Representative Concentration Pathways:
- http://www.skepticalscience.com/docs/RCP_Guide.pdf
- **Climate feedbacks:** How will changes to one Earth system affect others?
- Students could research how the following phenomena are related to positive and negative climate feedbacks: ice and land reflectivity (albedo), clouds, plant growth, and precipitation.
- **Media literacy:** Are the arguments about climate change presented in news stories based on reliable data?
- Students can use what they learned in this unit to evaluate and critique the claims, evidence, and reasoning about climate change that are presented in the news, magazines, or websites.

Activity 6.3: Human Energy Systems Posttest (20 min)

Tab 1: Overview and Preparation

Target Student Performance

Students show their initial proficiencies for the overall unit goals:

1. Questioning, investigating, and explaining how the Earth's climate is changing
2. Explaining and predicting how carbon cycles and energy flows in Earth systems.

Resources You Provide

- Pencils (1 per student, for paper version)

Resources Provided

- 6.3 Human Energy Systems Unit Posttest
- 6.3 Grading the Human Energy Systems Unit Posttest

Setup

Print one copy of the 6.3 Human Energy Systems Unit Posttest for each student.

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

1. Describe the unit posttest.

Explain the purpose of the unit posttest to students:

- It will help you as a teacher understand how students think about why and how carbon dioxide levels are increasing in the atmosphere.
- It will help them think about what they learned and how their ideas changed over time.

2. Have students take the unit posttest.

Distribute copies of 6.3 Human Energy Systems Unit Posttest to be completed with paper and pencil.

Tab 3: Assessment

Students should be able to answer the questions correctly, so it is reasonable to grade them at this point. Use 6.3 Grading the Human Energy Systems Unit Posttest to check student answers.

Tab 4: Differentiation & Extending the Learning

Differentiation (Accordion)

- Read the questions aloud to the class. Reframe or reword questions for clarity.
- Provide sentence stems for written responses.
- Provide visual aids if needed.

Modifications (Accordion)

Extending the Learning (Accordion)