Ocean Acidification and Its Impacts

Materials

For the leader:

Computer

Projector

For the activity:

Ocean Acidification Data Figures

Ocean Acidification & Calcifying Organisms Data Figure

Ocean Acidification Non-Calcifying Organisms Data Figure

Overview

Human activities (burning of fossil fuels, deforestation, cement production) have driven the rapid 40% increase in atmospheric carbon dioxide CO_2, from preindustrial levels of 280 ppmv (parts per million volume) to current levels of nearly 400 ppmv. Present-day atmospheric CO_2 concentration is projected to double by the end of the 21st century. Nearly one-third of the emitted anthropogenic CO_2 is absorbed by the oceans, resulting in alterations in carbonate chemistry (i.e., reductions in carbonate, CO_3^{2-}, ions) and reductions in seawater pH. This shift in the ocean towards more acidic conditions is known as ocean acidification. The faster the increase of CO_2 in the atmosphere, the faster the acidification of the ocean. Currently, the rate of oceanic CO_2 uptake and acidification is so rapid that it is at least ten times faster than any change seen in the fossil record over the past 65 million years.

The rapid changes in CO_2 uptake and acidification are expected to cause adverse ecosystem wide effects. One consequence of ocean acidification is the decrease in the availability of carbonate ions in the ocean. The reduction in carbonate ions makes it more difficult for calcifying organisms, which use calcium carbonate to form their shells, to grow and survive. Damage to the shells and skeletons of mollusks and corals has been observed as a result of ocean acidification. Additionally, ocean acidification has a wide-ranging potential for impacting the physiology and metabolism of both calcifying and non-calcifying marine organisms. Sufficiently elevated CO_2 concentrations/decreased pH levels can alter internal acid-base balance, compromising homeostatic regulation and disrupting internal systems ranging from oxygen transport to ion balance and metabolism. Much of scientists' current research on ocean acidification focuses on how organisms respond to increased CO_2 /decreased pH and if they can acclimate or adapt to these changes.

Motivating Questions:

- **What is the evidence that ocean acidification is happening?**
- **What are some of the consequences of ocean acidification on different marine organisms?**

Take Home Message

Ocean acidification results from increased levels of carbon dioxide dissolving into the ocean, which lowers the pH of the ocean (makes the water more acidic). This acidification process impacts oceanic organisms that use calcification to make their shells as well as the physiology of other organisms. Scientists use a range of data sets to understand the process and consequences of ocean acidification.

Structure

The students will be exposed to a range of data on ocean acidification. Students will work through multiple published data visuals to explore the evidence that ocean acidification is occurring and the impacts to calcifying and non-calcifying organisms.

Time Required

One 45-minute class period

Activity Outline

Engage: Students will participate in a brainstorming session about ocean acidification and the potential impacts.	10 minutes
Explore: Students will interpret a range of data to explore the process and potential implications or consequences of ocean acidification.	25 minutes
Make Sense: Through a class discussion students will reflect upon the data to process what they have learned about how ocean acidification works and the potential impacts of ocean acidification on organisms.	10 minutes
Total:	**45 minutes**

Audience

Middle school students (6th-8th grade).

New Jersey Core Curriculum Content Standards - Science

Content Area	Content Statement	CPI#
Science Practices: Understand Scientific Explanations	Results of observation and measurement can be used to build conceptual-base models and to search for core explanations.	5.1.8.A.2
	Predictions and explanations are revised based on systematic observations, accurate measurements, and structured data/evidence.	5.1.8.A.3
Science Practices: Generate Scientific Evidence Through Active Investigations	Mathematics and technology are used to gather, analyze, and communicate results.	5.1.8.B.2
	Carefully collected evidence is used to construct and defend arguments.	5.1.8.B.3
	Scientific reasoning is used to support scientific conclusions.	5.1.8.B.4
Science Practices: Reflect on Scientific Knowledge	Scientific models and understandings of fundamental concepts and principles are refined as new evidence is considered.	5.1.8.C.1
	Predictions and explanations are revised to account more completely for available evidence.	5.1.8.C.2
	Science is a practice in which an established body of knowledge is continually revised, refined, and extended.	5.1.8.C.3
Science Practices: Participate Productively in Science	Science involves practicing productive social interactions with peers, such as partner talk, whole-group discussions, and small-group work.	5.1.8.D.1
	In order to determine which arguments and explanations are most persuasive, communities of learners work collaboratively to pose, refine, and evaluate questions, investigations, models, and theories (e.g., argumentation, representation, visualization, etc.).	5.1.8.D.2
Life Science: Interdependence	Various human activities have changed the capacity of the environment to support some life forms.	5.3.6.C.1
	The number of organisms and populations an ecosystem can support depends on the biotic resources and on abiotic factors, such as quantities of light and water, range of temperatures, and soil composition.	5.3.6.C.2
Earth Systems Science: Biogeochemical Cycles	An ecosystem includes all of the plant and animal populations and nonliving resources in a given area. Organisms interact with each other and with other components of an ecosystem	5.4.6.G.2
	Personal activities impact the local and global environment.	5.4.6.G.3
	Investigations of environmental issues address underlying scientific causes and may inform possible solutions.	5.4.8.G.2

Preparation (20 minutes)

1. Write the motivating questions up on the board:

Q. What is the evidence that ocean acidification is happening?

Q. What are some of the consequences of ocean acidification on different marine organisms?

2. Write the Engage questions on the board:
    a. What do you know about ocean acidification?
    b. What do you want to know about ocean acidification?
3. Write the Make Sense questions on the board:
    a. In general, what did you learn about ocean acidification?
    b. What questions do you still have about ocean acidification?
4. Make enough copies of the "Ocean Acidification Data Figures" so that each small group receives one figure from the set. Make enough copies of the "Ocean Acidification & Calcifying Organisms Data Figure" and "Ocean Acidification & Non-Calcifying Organisms Data Figure" so that each small group gets a copy of both figures.
5. Write the data figure prompting questions on the board or an overhead sheet (and if possible keep covered from the students until you will use them):
    a. What is included in the figure?
    b. What conclusions did you draw from the figure?
    c. What does your figure tell us about the story of ocean acidification?

Engage (10 minutes)

1. Have the students think to themselves and write down their thoughts about the Engage questions on the board:
    a. What do you know about ocean acidification?
    b. What do you want to know about ocean acidification?
2. After a few minutes ask for volunteers to share their current knowledge or questions about ocean acidification. Be accepting of all responses and questions, as this is just a brainstorming activity to get the students thinking about ocean acidification.

Explore (25 minutes)

1. Tell the students that you will be looking at multiple datasets that scientists are using to determine whether ocean acidification is occurring and its effects.
2. The students will work in small groups to interpret a dataset. Each group will be given different datasets. The students need to work together to understand their dataset, draw conclusions from this data visualization, and determine what piece of the ocean acidification story their data visualization tells. The students will present their data visualization to the class at the end of their 5 minutes.
3. Pass out the "Ocean Acidification Data Figures" to each small group.
4. As the students are talking through their data visualizations, circulate and answer questions as needed.
    a. Atmospheric CO_2 and Global Ocean pH – The figures were made by the Intergovernmental Panel on Climate Change (IPCC). The top graph in Figure 1 shows projected atmospheric CO_2 levels from 2000 to 2100 and the bottom graph shows projected global ocean pH levels for the same

timeframe. The different lines represent the different emission scenarios that went into the model. Figure 2 is a summary of the factors that went into each model.

b. pH and Oceanic Dissolved Carbon Dioxide – The graph combines historical data with future predictions made using models to show changes in pH and dissolved carbon dioxide in the ocean over time. For reference, the scale on the left shows the pH of some common liquids.

c. Atmospheric CO_2 Over Time – The graph shows atmospheric carbon dioxide levels from the 1800s to predicted levels in 2300. Two different Intergovernmental Panel on Climate Change (IPCC) models are used in this figure. IS92a uses carbon dioxide emissions that continue at today's rate. S650 uses carbon dioxide emissions that decrease and eventually become steady.

5. After five minutes have passed (or as the students begin to wrap-up their work), have each group report to the class what they were interpreting and their responses to the three prompting questions:
    a. What is included in the figure?
    b. What conclusions did you draw from the figure?
    c. What does your figure tell us about the story of ocean acidification?
6. Have the students work together to use the different pieces of data to understand the relationship below.

Atmospheric CO_2 is increasing over time

↓

Increase in the amount of dissolved CO_2 in the oceans

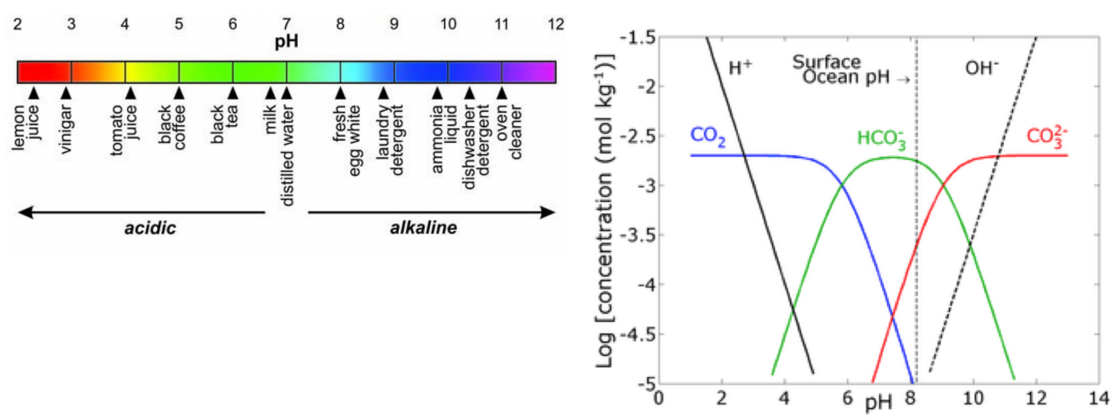
↓

Decreases oceanic pH

Note – it might be helpful to write this on the board as the students are reporting out about their data visualizations.

7. Project the "Dissolved CO_2, HCO^{3-}, CO_3^{2-}, and pH" figure on the board.

$$H_2O + CO_2 \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+ \rightarrow 2\,H^+ + CO_3^{2-}$$



(Zeebe, R. and J.-P. Gattuso. 2009. Marine Carbonate Chemistry. In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment)

8. Explain to the students that they are looking at in the graph on the right is what is called a Bjerrum (b-yair-rum) plot. Help the students interpret the plot by asking:

   a. What is the variable that we can "control" by increasing or decreasing its value? (This is the independent variable.)

      The students should see that we are looking at the effects of changing pH. As we move towards the right side of the graph the pH becomes more basic, like dishwasher detergent, and there is an increase in the amount of OH^- ions (dashed black line). As we move to the left side of the graph the pH becomes more acidic, like vinegar, and there is an increase in the amount of H^+ ions (solid black line).

   b. What are the variables that are changing in response to differences in pH? (These are the dependent variables.)

      The students should see that the concentration of dissolved carbon dioxide (CO_2), bicarbonate (HCO^{3-}), and carbonate (CO_3^{2-}) is changing due to differences in pH. It may be helpful to explain in words what these are to your students and point out that the letters represent the different elements that are in the molecules.

   c. What is the average pH of the ocean currently?

      The average pH of the ocean is 8, as indicated by the dotted black line and "Surface Ocean pH" label.

   d. Knowing what we now know about ocean acidification, in which direction would the average ocean pH move in the future?

      As the ocean pH decreases, the dotted line will move to the left side of the figure. Note – it may be helpful to draw that on the project of the figure with a marker or with your finger. It is also a good opportunity to remind students that pH is measured on a log scale, so a .1 change in pH is roughly a 30% change in acidity.

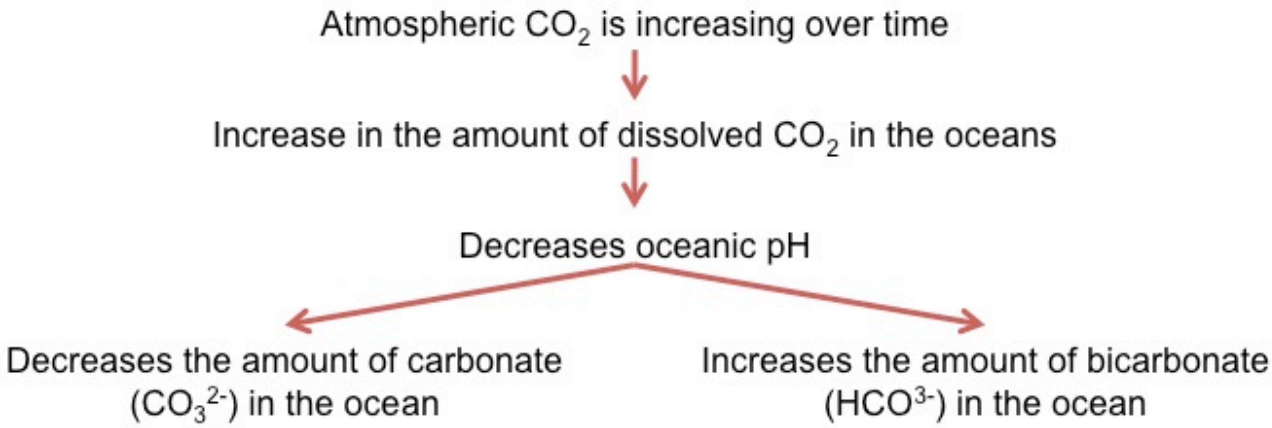
   e. What relationship can you see between a decrease in pH and the amount of Hydrogen (H+) ions that are in the water?

      The students should see again that the H+ ions increase as the pH decreases. Help the students to see in the chemical equation for ocean acidification at the top that 3 hydrogen ions are formed in the reactions to help them see the connection of increases in the number of H+ ions decreases the pH and thus makes the ocean more acidic.

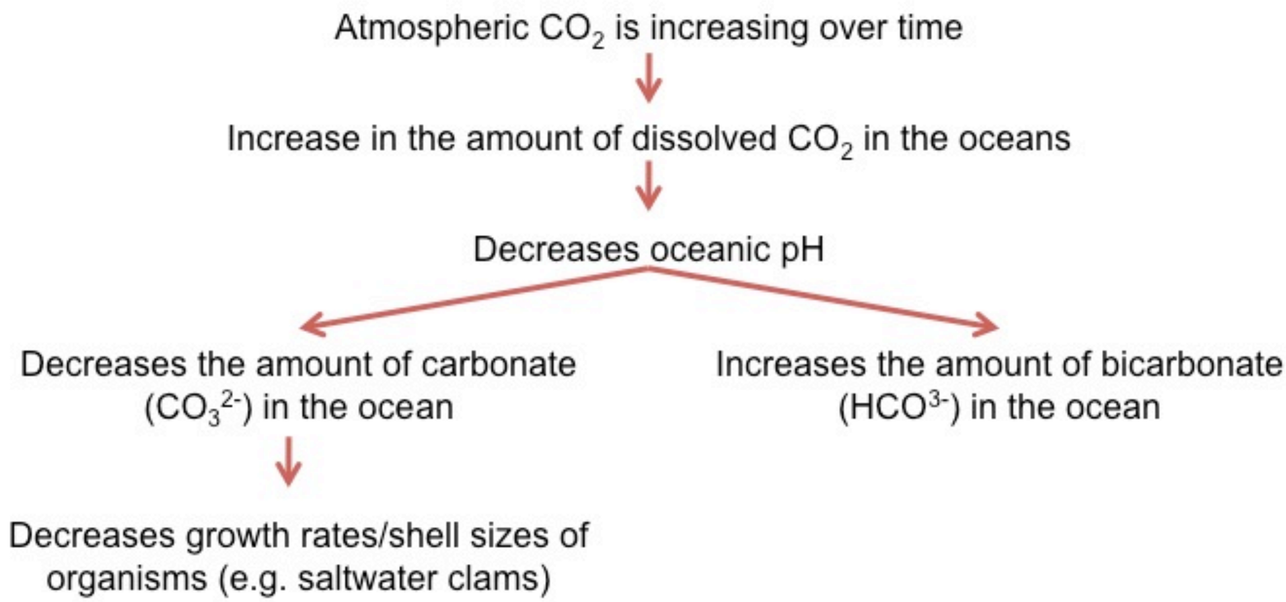
   f. What could happen to the concentrations of different carbon molecules in the ocean due to the decrease in pH?

      The students should observe that as the pH decreases the concentration of carbonate (CO_3^{2-}) ions decreases. In addition, the concentration of bicarbonate (HCO^{3-}) ions increases (note – this is harder to see so you may need to point it out to your students).

9. Have the students work together to use the different pieces of data to add to their understanding that: (Note – add to the model already on the board as the students report out their findings).



10. Take a 30 second break to let the students get up and walk around ☺, while the students are taking their break make sure you have the "Ocean Acidification & Calcifying Organisms Data Figure" and the "Ocean Acidification & Non-Calcifying Organisms Data Figure" for the students.
11. Have the students return to their data interpretation small groups and pass out the "Ocean Acidification & Calcifying Organisms Data Figure" to each small group. Inform the students that they will be now be looking at additional data for the impacts of ocean acidification on organisms that need carbonate to make their shells (calcifiers).
12. As the students are talking through the data visualization, answer questions as needed.
    a. Saltwater Clam Grown Under Different CO_2 Concentrations – The scanning electron microscopy (SEM) images are of saltwater clams (*M. mercernaria*) that were grown in different CO_2 levels for 36 days ranging from 250-1500 ppm.
13. After five minutes have passed (or as the students begin to wrap-up their work), have each group report to the class what they were interpreting and their responses to the three prompting questions:
    a. What is included in the figure?
    b. What conclusions did you draw from the figure?
    c. What does your figure tell us about the story of ocean acidification?
14. Have the students work together to use the different pieces of data to build upon their understanding of ocean acidification to include the following impacts on calcifying organisms: (Note - add to the model already on the board as the students report out their findings.)



Note – It is important to realize, and some of your students may bring this up, that the relationships as demonstrated in the published data is correlative and not cause and effect to demonstrate the students the potential impacts of ocean acidification we have included it in this manner in the activity.

15. Ask the students if they think other organisms in the ocean, those that do not use calcium carbonate for their shells or skeletons, would be impacted by ocean acidification. Have the students talk with a neighbor for a minute about it, before pulling everyone back together.

16. Ask for volunteers to share what they and their partner were discussing. Be accepting of all responses. This is just a brainstorming activity to get students to think about other potential impacts of ocean acidification.

17. Pass out the "Ocean Acidification & Non-Calcifying Organisms Data Figure" to each small group. Inform the students that they will now be looking at data on the impacts of ocean acidification on organisms that do not use the carbonate in the water to form shells or skeletons (non-calcifiers).

    Note – Depending on the prior knowledge of your students, make sure they understand that the amount of proteins an organism has within its cells is critical for the overall health of the organism. A decrease in the amount of proteins can stress the organism.

18. As the students are talking through the data visualization, answer questions as needed.

    a. Feeding Rate, Excretion Rate, and Proteins – The figures show (a) feeding rates (ingestion), (b) excretion rates, and (c) amount of protein in Antarctic krill (*Euphausia superba*) exposed to current (ambient) CO_2 conditions of 325 ppm (white) and high CO_2 conditions of 672 ppm (black).

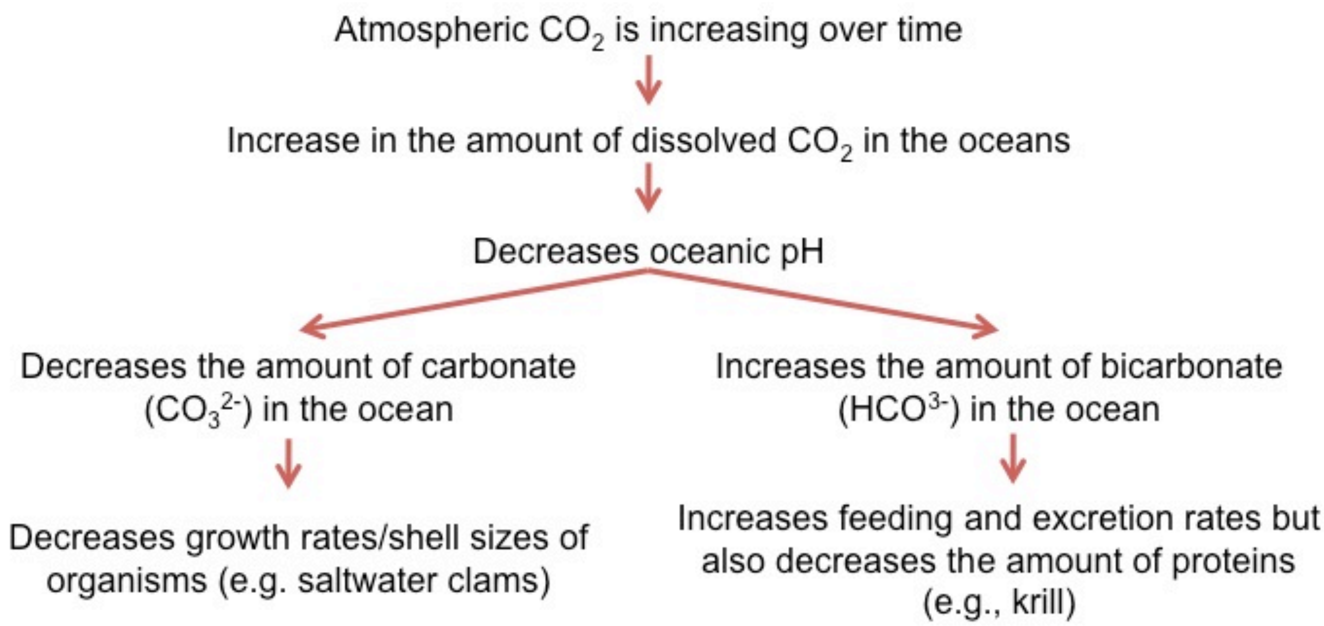
19. After five minutes have passed (or as the students begin to wrap-up their work), have each group report to the class what they were interpreting and their responses to the three prompting questions:

    a. What is included in the figure?

    b. What conclusions did you draw from the figure?

    c. What does your figure tell us about the story of ocean acidification?

20. Have the students work together to use the different pieces of data to build upon their understanding of ocean acidification to include the impacts on non-calcifying organisms such that: (Note - add to the model already on the board as the students report out their findings.)



Make Sense (10 minutes)

1. Have the students think to themselves and write down their thoughts about the Make Sense questions on the board:
    a. In general, what did you learn about ocean acidification?
    b. What questions do you still have about ocean acidification?
2. After a few minutes ask for volunteers to share what they learned or questions they still have about ocean acidification. Be accepting of all responses and questions, as this is just a reflection and processing activity to get the students to think about how they have spent the last 40 minutes learning about ocean acidification.
3. Once the discussion slows down, point to the motivating questions and ask:

    Q. What is the evidence that ocean acidification is happening?

    Q. What are some of the consequences of ocean acidification on different marine organisms?
4. Ask students to share their ideas about the questions with a partner. After a minute, ask volunteers to share the ideas they discussed with the entire class. Be accepting of all responses from the students. This is your opportunity to make sure the students understand the "take home message" of the section. Make sure the students have processed that:
    a. Ocean acidification is due to an increase in the amount of dissolved carbon dioxide in the ocean. The increase in the amount of dissolved carbon dioxide decreases the oceanic pH (making the water more acidic).
    b. A decrease in the oceanic pH is coupled with a decrease in the available carbonate ions in the water, which means there is less carbonate available for organisms that use calcium carbonate to make their shells.

   c. A decrease in the oceanic pH is coupled with an increase in the available bicarbonate and hydrogen ions in the water, which means that there is an increase in the metabolic function of organisms so they may eat more but they are not getting as many proteins.

5. Ask if the students have any final questions about the activities and presentations of the day.

Common Core State Standards Connections: ELA/Literacy and/or Math

English Language Arts

RST.6-8.1	Cite specific textual evidence to support analysis of science and technical texts.
RI.8.8	Trace and evaluate the argument and specific claims in a text, assessing whether the reasoning is sound and the evidence is relevant and sufficient to support the claims.
WHST.6-8.1	Write arguments to support claims with clear reasons and relevant evidence.
WHST.6-8.9	Draw evidence from literary or informational texts to support analysis, reflection, and research.
SL.8.5	Include multimedia components and visual displays in presentations to clarify claims and findings and emphasize salient points.

Mathematics

MP.2	Reason abstractly and quantitatively.
6.EE.B.6	Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set.
6.EE.C.9	Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation.
7.EE.B.4	Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities.

Next Generation Science Standards

Ecosystems: Interactions, Energy, and Dynamics, MS-LS2-3 – Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

Science & Engineering Practice	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models – Use a model to provide mechanistic accounts of phenomena.	*LS3.B Cycle of Matter and Energy Transfer in Ecosystem* – Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at	*Energy and Matter* - The transfer of energy can be tracked as energy flows through a natural system. *Scientific Knowledge Assumes an Order and Consistency in Natural Systems* - Science assumes that objects and events in natural systems occur in consistent patterns

	every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.	that are understandable through measurement and observation.

Ecosystems: Interactions, Energy, and Dynamics, MS-LS2-4 – Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

Science & Engineering Practice	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Engaging in Argument from Evidence - Construct an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.	*LS2.C: Ecosystem Dynamics, Functioning, and Resilience* - Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations.	*Stability and Change* - Small changes in one part of a system might cause large changes in another part.

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.

Science & Engineering Practice	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Asking Questions and Defining Problems - Ask questions to identify and clarify evidence of an argument.	*ESS3.D: Global Climate Change* - Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and on applying that knowledge wisely in decisions and activities.	*Stability and Change* – Stability might be disturbed either by sudden events or gradual changes that accumulate over time.