Impacts of Ocean Acidification

Materials

For the leader:

Computer

Projector

For the activity:

Ocean Acidification Data Figures

Ocean Acidification & Calcifying Organisms Data Figures

Ocean Acidification & Non-Calcifying Organisms Data Figures

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 have 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 potential consequences of ocean acidification on calcifying and non-calcifying organisms?**

Take Home Message

Ocean acidification results from increased levels of carbon dioxide dissolving into the ocean, which lowers the pH of the ocean. 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.	5 minutes
Explore: Students will interpret a range of data to explore the process and potential implications or consequences of ocean acidification.	30 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

High school students (9th-12th grade).

New Jersey Core Curriculum Content Standards - Science

Content Area	Content Statement	CPI#
Science Practices: Understand Scientific Explanations	Mathematical, physical, and computational tools are used to search for and explain core scientific concepts and principles.	5.1.12.A.1
	Interpretation and manipulation of evidence-based models are used to build and critique arguments/explanations.	5.1.12.A.2
	Revisions of predictions are based on explanations are based on systematic observations, accurate measurements, and structures data/evidence.	5.1.12.A.3
Science Practices: Generate Scientific Evidence Through Active Investigations	Empirical evidence is used to construct and defend arguments.	5.1.12.B.3
Science Practices: Reflect on Scientific Knowledge	Refinement of understands, explanations, and models occurs as new evidence is incorporated.	5.1.12.C.1
	Data and refined models are used to revise predications and explanations.	5.1.12.C.2
	Science is a practice in which an established body of knowledge is continually revised, refined, and extended as new evidence emerges.	5.1.12.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.	5.1.12.D.1
	Science involves using language, both oral and written, as a tool for making thinking public.	5.1.12.D.2.
Physical Science: Properties of Matter	Acids and bases are important in numerous chemical processes that occur around us, from industrial to biological processes, from the laboratory to the environment.	5.2.12.A.6
Life Science: Organization and Development	Cellular function is maintained through the regulation of cellular processes in response to internal and external environmental conditions.	5.3.12.A.3
Life Science: Interdependence	Stability in an ecosystem can be disrupted by natural or human interactions.	5.3.12.C.2
Earth Systems Science: Climate and Weather	Climate is determined by energy transfer from the Sun at and near Earth's surface. This energy transfer is influenced by dynamic processes, such as cloud cover and Earth's rotation, as well as static conditions, such as proximity to mountain ranges and the ocean. Human activities, such as the burning of fossil fuels, also affect the global climate.	5.4.12.F.2

Earth Systems Science: Biogeochemical Cycles	Natural and human-made chemicals circulate with water in the hydrologic cycle.	5.4.12.G.1
	Natural and human activities impact cycling of matter and the flow of energy through ecosystems.	5.4.12.G.4
	Human activities have changed Earth's land, oceans, and atmosphere, as well as its populations of plant and animal species.	5.4.12.G.5
	Earth is a system in which chemical elements exist in fixed amounts and move through the solid Earth, oceans, atmosphere, and living things as part of geochemical cycles.	5.4.12.G.7

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 potential consequences of ocean acidification on calcifying and non-calcifying 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," "Ocean Acidification & Calcifying Organisms Data Figures," and "Ocean Acidification & Non-Calcifying Organisms Data Figures" so that each small group can receive one figure from each set of 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 (5 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 (30 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 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 concentrations that increase at 1% per year after 1990 and carbon dioxide emissions that continue at today's rate. S650 uses carbon dioxide emissions that decrease and eventually stabilize (a stabilization scenario).
   b. Atmospheric CO_2 and Global Ocean pH – The graph shows different model scenario based upon population, economic growth, etc. as predicted 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.
   c. pH and Oceanic Dissolved Carbon Dioxide – The graph combines historical data with predictions made using models to show changes in pH and oceanic dissolved carbon dioxide over time. For reference, the scale on the left shows the pH of some common liquids.
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

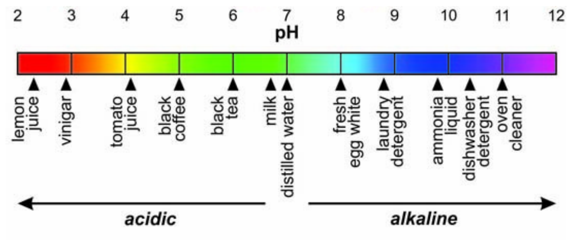
↓

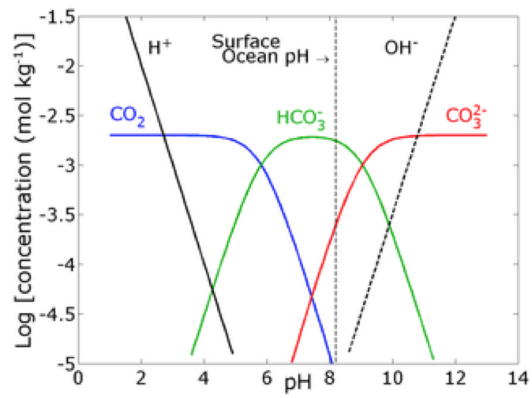
Decreases oceanic pH

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 independent variable? Or said another way, what is the variable that we can "control" by increasing or decreasing its value?

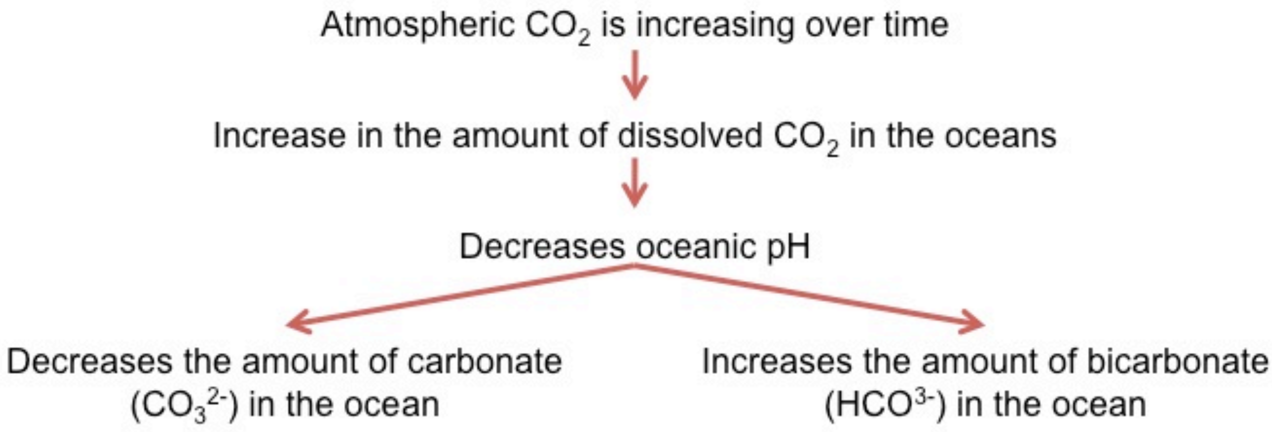
       The students should see that we are looking at the effects of changing pH. As we move towards the right side of the graph the pH becomes more basic and there is an increase in the amount of OH^- ions. As we move to the left side of the graph the pH becomes more acidic and there is an increase in the amount of H^+ ions.
    b. What are the dependent variables? Or said another way, what are the variables that are changing in response to differences in pH?

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

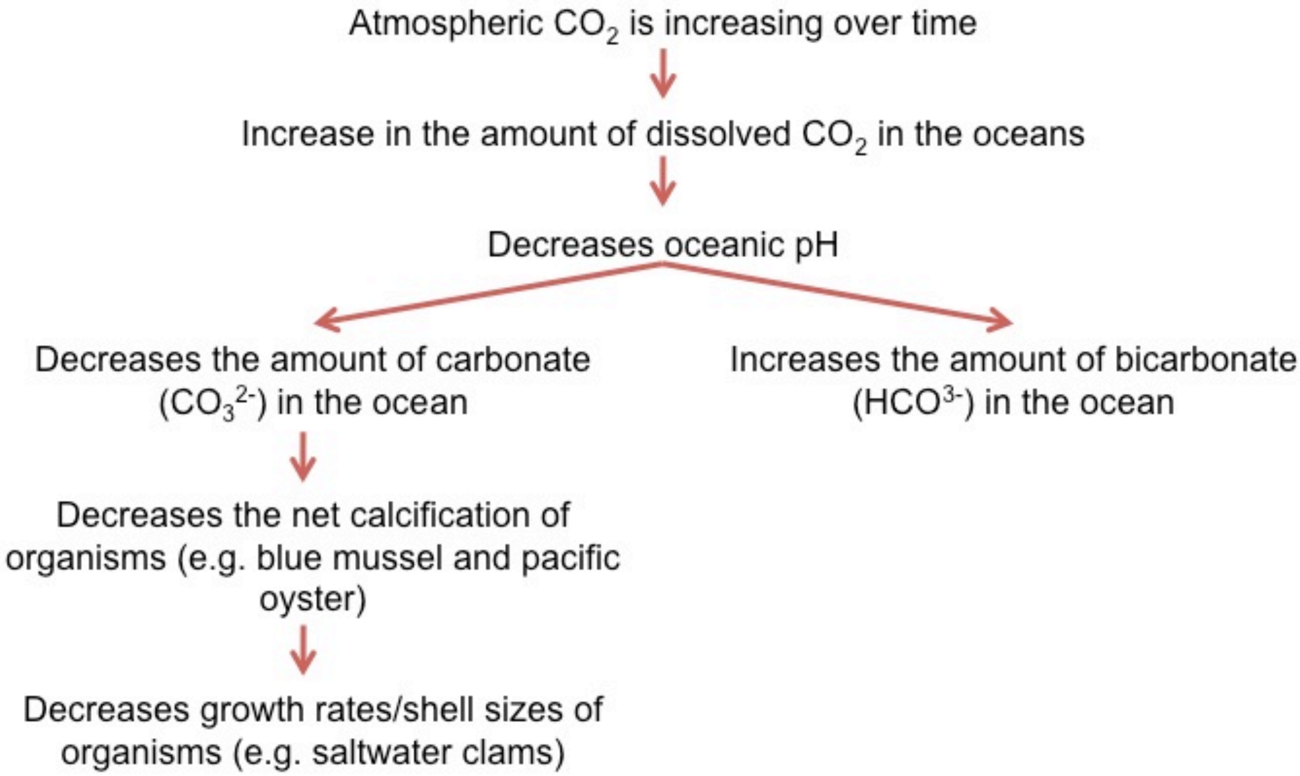
       The average pH of the ocean is 8, as indicated by the dotted black line and the "Surface Ocean pH" label.
    d. Knowing what we now know about ocean acidification and how it will impact ocean pH, in which direction would the average ocean pH move in the future?

       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 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 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 Figures" and the "Ocean Acidification & Non-Calcifying Organisms Data Figures" for the students.
11. Have the students return to their data interpretation small groups and pass out the "Ocean Acidification & Calcifying Organisms Data Figures" to each small group. Inform the students that they will be now be looking at additional data on the impacts of ocean acidification on organisms that need carbonate to make their shells (calcifiers).
12. As the students are talking through their data visualizations, answer questions as needed.
    a. Net Calcification, CO_2, Carbonate (CO_3^{2-}), and pH – The graphs show the relationship between net calcification and partial pressure CO_2, carbonate ion concentration, and pH for *Mytilus edulis* (blue mussel) and *Crassostrea gigas* (pacific oyster).
    b. *M. mercenaria* Grown Under Different CO_2 Concentrations – Scanning electron microscopy (SEM) images of *M. mercernaria* (saltwater clam species) 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.)

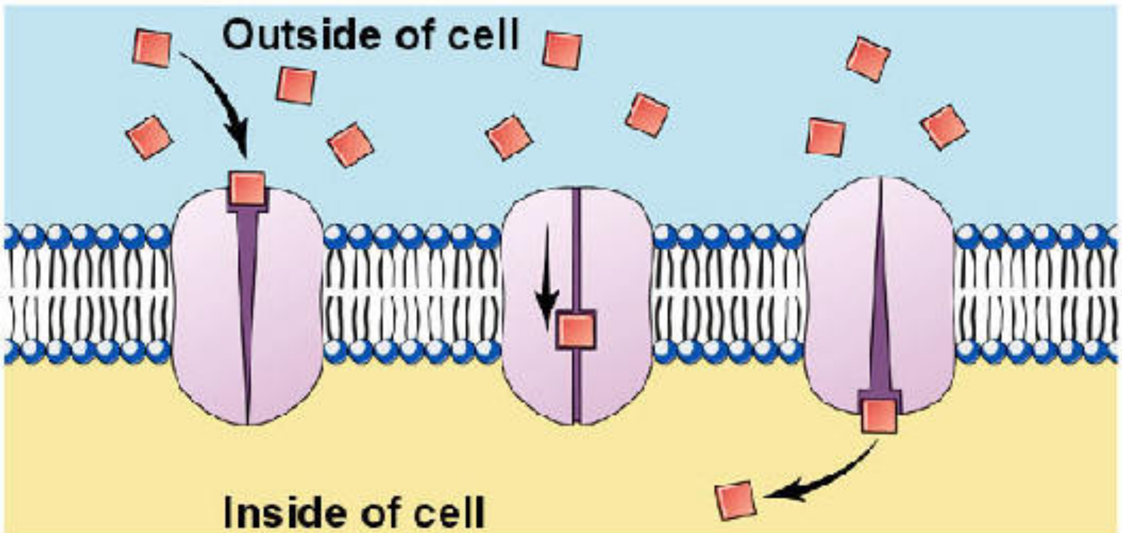


Note – It is important to realize, and some of your students may bring this up, that these relationships as demonstrated in the published data are correlative and not cause and effect to demonstrate the students the potential impacts of ocean acidification we have included them in this manner in the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

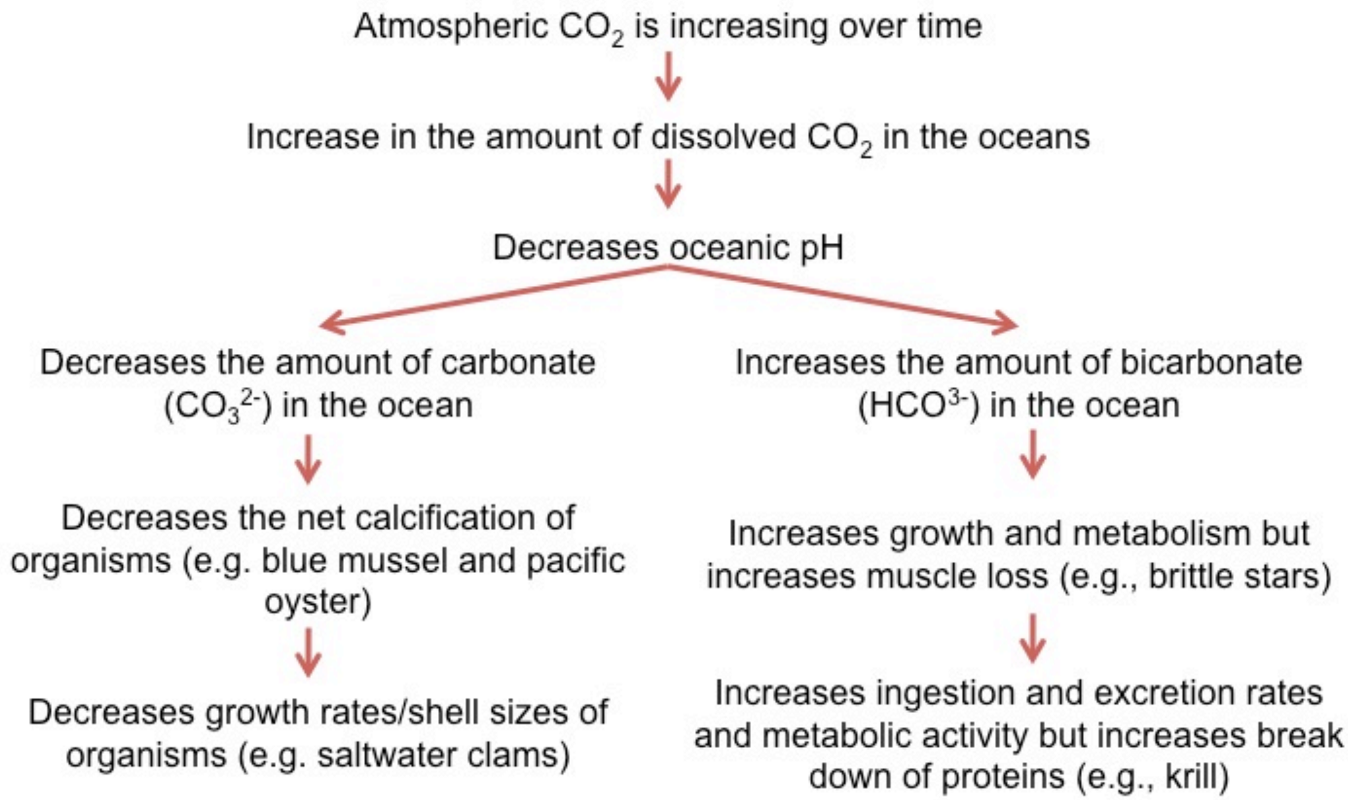
15. Ask the students if they think other organisms in the ocean, those that do not use calcium carbonate for their shells or skeletons, would be impacted by ocean acidification. Have the students talk with a neighbor for a minute about it, before pulling everyone back together.
16. Ask for volunteers 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 Figures" 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 (and what you would like them to get out of the non-calcifying organisms data figures), you may want to make sure they understand that with a decrease in pH there is an influx of H+ ions through the membrane and bicarbonate ions accumulate within cells. Organisms that live in water rely almost entirely on ion exchange mechanisms to maintain their equilibrium or acid-base balance within cells. Therefore, ion regulation works to re-establish the original or new equilibrium in the cell fluids. This effort to equilibrate, or compensate, for these changes causes large and perhaps unfavorable changes in the ionic composition of plasma and other body fluids. This can cause a decrease in protein synthesis rate, decrease in heart and muscle function, and increases or decreases in ventilation, or breathing rate.

However, an increase in H+ ions can also result in an increase in the metabolism of organisms as observed by increased growth rate, oxygen uptake, and other functions of organisms. If you would like to show them an image of ion exchange mechanisms you can project this image.



18. As the students are talking through their data visualizations, answer questions as needed.
    a. Oxygen Uptake, Arm Regeneration, and Muscle Tissue – The graphs show the impact of seawater pH on (a) oxygen uptake (µmol per day per gram animal) and (b) length of arm regeneration (mm) following a 40-day exposure of ophiuroid brittlestar (*Amphiura filiformis*). The images show longitudinal cross sections of established arms at ×10 mag, mounted in resin and stained.
    b. Ingestion Rate, DOC Release Rate, and Proteins – The figures show (a) krill ingestion rates, (b) dissolved organic carbon release rates, and (c) protein of Antarctic krill (*Euphausia superba*) exposed to current (ambient) CO_2 conditions of 325 ppm (white) and high CO_2 conditions of 672 ppm (black). X and Y indicate that there are significant differences in the measurements of each condition.
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 potential consequences of ocean acidification on calcifying and non-calcifying 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 grow faster but also may loose muscle tissue or proteins as a result.

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

SL.11-12.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.
RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
RST.11-12.2	Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

Mathematics

MP.2	Reason abstractly and quantitatively.
MP.4	Model with mathematics.
HSN.Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
HSN.Q.A.2	Define appropriate quantities for the purpose of descriptive modeling.
HSN.Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

Next Generation Science Standards

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

Science & Engineering Practice	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data – Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal	*ESS2.A Earth Materials and Systems* – Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.	*Stability and Change* – Feedback (negative or positive) can stabilize or destabilize a system.

design solution.		

Earth's Systems, 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.

Science & Engineering Practice	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models – Use a model to provide mechanistic accounts of phenomena. *Scientific Knowledge is Based on Empirical Evidence* – Science arguments are strengthened by multiple lines of evidence supporting a single explanation.	*ESS2.A Earth Materials and Systems* – The geological record shows that changes to global and regional climate can be cause by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetations, and human activities.	*Cause and Effect* – Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Earth's Systems, HS-ESS2-6 – Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

Science & Engineering Practice	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models – Develop a model based on evidence to illustrate the relationships between systems or between components of a system.	*ESS2.D Weather and Climate* – Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. - Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.	*Energy and Matter* – The total amount if energy and matter un closed systems is conserved.

Earth and Human Activity, HS-ESS3-5 – Analyze geosciences data and the result 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.

Science & Engineering Practice	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data – Analyze data using computational models in order to make valid and reliable scientific claims. *Scientific Investigations Use a Variety of Methods* – Science investigations use diverse methods and do not always use the same set of procedures to obtain data.	*ESS3.D Global Climate Change* – Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.	*Stability and Change* – Change and rates of change can be quantifies and modeled over very short or very long periods of time. Some system changes are irreversible.

Scientific Knowledge is Based on Empirical Evidence – Science knowledge is based on empirical evidence. - Science arguments are strengthened by multiple lines of evidence supporting a single explanation.		

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.

Science & Engineering Practice	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Using Mathematics and Computational Thinking – Use a computational representation of phenomena or design solutions to describe and/or support claims and/or explanations.	*ESS2.D Weather and Climate* – Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. *ESS3.D Global Climate Change* – Through computer simulation and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.	*Systems and System Models* – When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.