Chemistry in the Earth System Unit 6

The Dynamics of Chemistry& Ocean Acidification

Background for Teachers and Instructional Suggestions

In earlier instructional segments, students developed an understanding that the chemical and physical structure of molecules is made from atoms bound together by the formation of chemical bonds. In this instructional segment students expand their understanding of chemical reactions as processes where these bonds are broken apart, typically because two or more molecules collide, and the atoms are rearranged, resulting in molecules with new properties. ***Matter is conserved*** in that the same set of atoms is present in the final state (product) as was there in the initial state (reactant). By the completion of this instructional segment, students are able to use stoichiometric principles as evidence of, and examples of, the conservation of matter. Students must be able to explain the relationship between the mathematics of chemical equations and the conservation of matter (*HS-PS1-7*). The most obvious way to accomplish this performance objective is by understanding and applying the basic principles of stoichiometry through laboratory **investigations**, problem solving, and reinforcement with apps and programs. The word "stoichiometry" derives from two Greek words: *stoicheion* (meaning "element") and *metron* (meaning "measure"). Stoichiometry is based upon the law of the conservation of mass and deals with calculations about the masses of reactants and products involved in a chemical reaction. While stoichiometry can be challenging to students and teachers alike, research shows that the more time students spent in high school chemistry on stoichiometry, the greater success they had in college chemistry courses on average (Tai, Sadler, and Loehr 2005).

The law of definite ***proportions***, sometimes called Proust's Law, states that a chemical compound always contains exactly the same proportion of elements by mass. An equivalent statement is the law of constant composition, which states that all samples of a given chemical compound have the same elemental composition by mass. Students must learn that compounds appear in whole-number ratios of elements and that chemical reactions result in the rearrangement of these elements into other whole-number ratios. Students can develop a deeper understanding of the principles involved in *HS-PS1-7* by massing and comparing the reactants and products of simple chemical reactions. For example, if students dehydrate copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) into the anhydrous salt ($CuSO_4$) by heating, they will find that the ratio of the mass of the resulting copper sulfate (dry mass) to water (the mass lost in dehydration) is always the same, regardless of how much copper sulfate pentahydrate is used. Students can infer that because the ratio of the component molecules in such a dehydration reaction remains constant, then the ratio of component elements must also remain constant. By applying **mathematical thinking**, students learn to balance chemical reactions and predict relative quantities of products.

This instructional segment on chemical reactions emphasizes the crosscutting concepts of ***stability and change***. ***Stability*** refers to the condition in which certain parameters in a system remain relatively constant, even as other parameters change. Dynamic equilibrium is an example of stability in which reactions in one direction are equal and opposite to those in the reverse direction, so although changes are occurring, the overall system remains stable. Dynamic equilibrium illustrates the principle of stability in an environment undergoing constant change. If, however, the inputs are sufficiently altered, a state of disequilibrium may result, causing significant changes in the outputs.

Once a disruption is made to a ***system***, the speed at which chemical reactions work to re-establish that equilibrium varies depending on a number of factors. Students must be able to gather evidence to **construct** a scientific **explanation** about what ***causes*** these speed variations (*HS-PS1-5*). In instructional segment 4, students **developed a model** of chemical reactions at the microscopic level that includes atoms colliding with one another and forming new bonds. Students can **investigate** the response of reaction rates to varying temperatures and concentrations of reactants (both of which make collisions between reactants more likely). For example, students can mix baking soda (sodium hydrogen carbonate, $NaHCO_3$) and vinegar (acetic acid, CH_3COOH) in sealed sandwich bags and gauge the speed and degree of reaction by the rate and amount of CO_2 gas produced as indicated by the swelling of the bag: $NaHCO_3 (aq) + CH_3COOH (aq) \rightarrow CO_2 (g) + H_2O (l) + CH_3COONa (aq)$. Students can

investigate the role of the quantity of molecular collisions by repeating the activity with differing concentrations of vinegar. They can then **investigate** the role of temperature by warming or cooling the reactants while keeping their concentrations constant. By observing the swelling of the bags in response to varying temperatures and concentrations, students should discover that those factors that increase the number and ***energy*** of molecular collisions (increased concentration and temperature of reactants) result in increased reaction rates. Combining a conceptual **model** with experimental **evidence**, students can thus provide reasoned **explanations** for factors influencing chemical reaction rates.

Once students understand the ***effect*** of changing the concentration of reactants and products on reaction rates, they are ready to apply their understanding to novel situations. Performance expectation *HS-PS1-6* requires students to "*refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium*". By applying Le Chatlier's principle, students can predict ways to increase the amount of product in a chemical reaction. In order to "*refine the design of a chemical system*", students must first be able to measure output and then test the effectiveness of changing the temperature and relative concentrations of reactants and products. For example, gas pressure is reduced and heat is given out when hydrogen and nitrogen combine to form ammonia (Figure 16). According to Le Chatlier's principle, the reaction can proceed to produce more ammonia by increasing the pressure and/or by dropping the temperature. Conversely, more ammonia will decompose into hydrogen and nitrogen by lowering the pressure and/or raising the temperature.

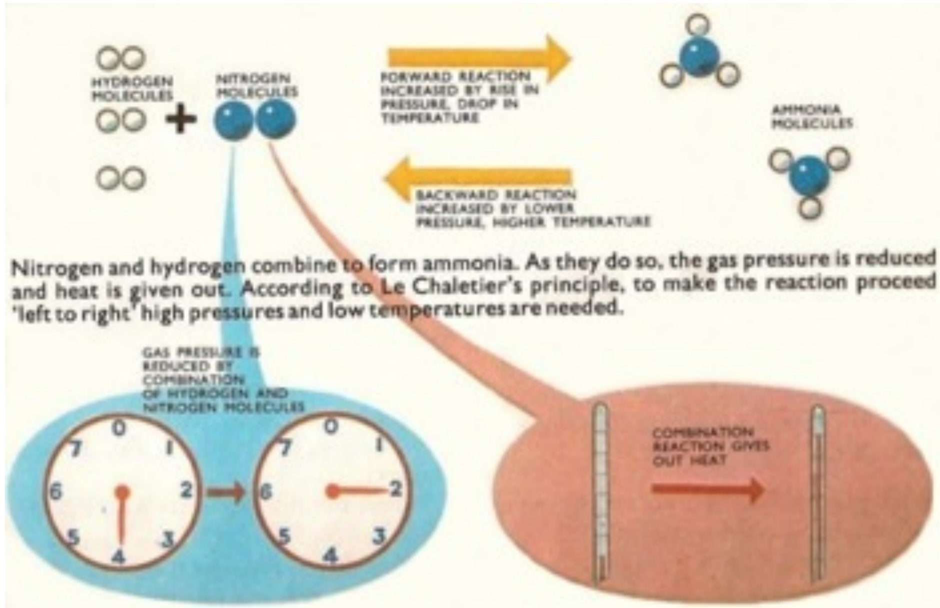

Figure 16 Students should be able to apply Le Chatlier's principle to predict ways to increase the product of a chemical reaction

As students tackle *HS-PS1-6*, they must invoke the engineering strategies specified in *HS-ETS1-2* in which they are required to "design a solution *to a complex real-world problem by breaking it down into smaller, more manageable problems"*. For example, students might be challenged to increase the amount of precipitated table salt in solution [$NaCl(s) \leftrightarrow Na^{+}(aq) + Cl^{-}(aq)$] without adding more salt. By experimenting with the addition of other sodium salts, students may discover that an increase in free sodium ions shifts the reaction in favor of the precipitate. To optimize the production of sodium, students may also experiment with ***changes*** in temperature, discovering that decreases in temperature favor the production of precipitate. In doing such **investigations**, students are applying the engineering skill of optimization as they refine their design to increase productivity.

Disrupting Equilibrium in the Ocean

Changes in the world's oceans bring together all science and engineering disciplines and are an excellent way to introduce principles of chemical dynamics. There are some excellent *CA NGSS* aligned resources for teaching about ocean chemistry, including well-designed curriculum sequences about ocean acidification[1]. A good activity sequence begins by **obtaining and evaluating information** in order to **define the problem** ***(****HS-ETS1-1****)***. In instructional segment 5, students saw evidence that human activities emit CO_2 in the atmosphere. While the concentration of CO_2 in our atmosphere is currently 40% higher than it was at the start of the Industrial Revolution, it would be even higher if it were not for the ocean. The ocean constantly exchanges CO_2 with the atmosphere so that the two are in equilibrium. As the atmospheric CO_2 goes up, this temporarily disrupts the balance and causes more CO_2 to enter the oceans than leave. Students can examine data showing trends in CO_2 concentrations in the ocean and atmosphere as evidence of a balancing feedback between two of Earth's ***systems*** that slows the rate of climate change (*HS-ESS2-2*). The ocean currently absorbs more than a quarter of the annual emissions of CO_2 from human activities. Students can add this fact to their quantitative **model** of the carbon ***cycle*** (*HS-ESS2-6,* ties to instructional segment 5 of the Life Science course).

In the ocean, CO_2 molecules have no impact on the atmospheric greenhouse effect. However, the ***changes*** in the ocean are significant (*EP&C Principles II, III, & IV*). Students can design a simple **investigation** to generate CO_2 (gas released by a baking soda/vinegar reaction, a combusting candle, or yeast foaming) and explore how it affects the pH using an indicator solution or probe. They find that the ocean becomes more acidic, so this environmental change is termed 'ocean acidification.' Students can also investigate the ***effect*** that temperature and salinity have on the ability of CO_2 to dissolve into the water (*HS-PS1-5*).

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[1] Institute for Systems Biology, Ocean Acidification: A Systems Approach to a Global Problem: http://baliga.systemsbiology.net/drupal/education/?q=content/ocean-acidification-systems-approach-global-problem

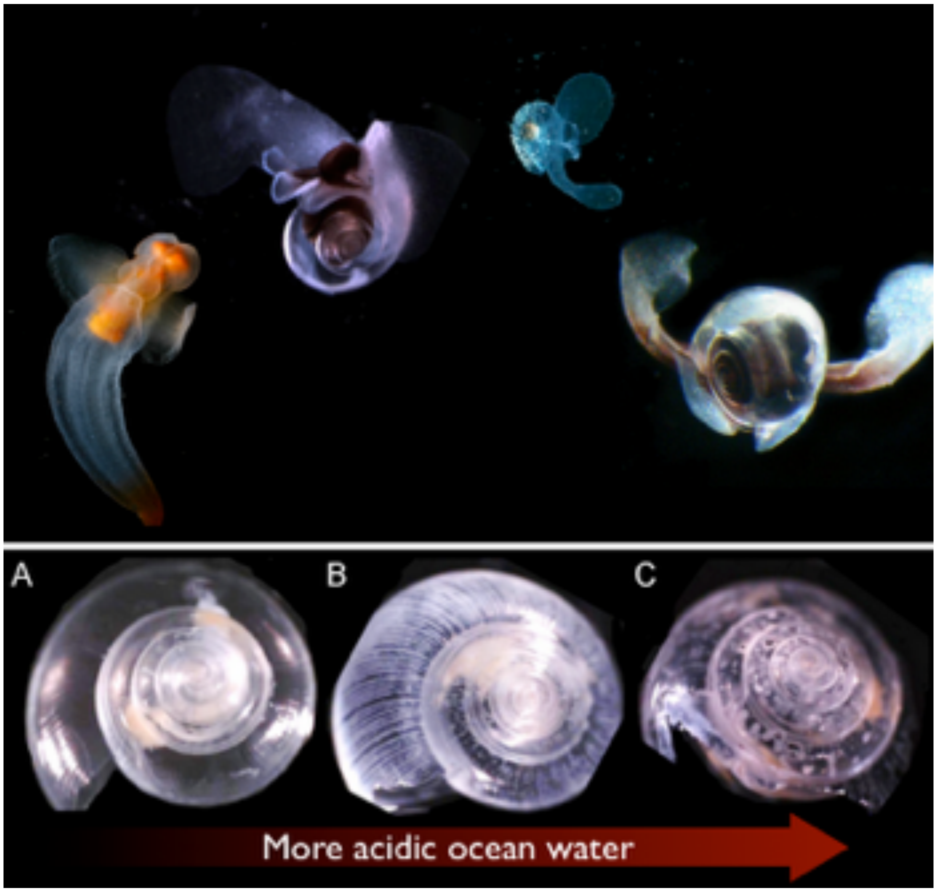


Figure 17. Pteropods are a delicate species of sea creature. The bottom panel shows laboratory experiments demonstrating how their shells dissolve when ocean water is too acidic. Image Credit: (NOAA Photo Library 2005;Hopcroft 2002; Auster and DeGoursey 2000; Hunt et al. 2010) Bottom: (CC0) by Busch et al. (2014), http://doi:10.1371/journal.pone.0105884

When CO_2 dissolves in the ocean, the situation is more complex because the CO_2 interacts with living organisms and other inorganic molecules in the seawater. Many rocks in Earth's crust are rich in calcium, so when rivers wash material towards the ocean they bring a rich supply of calcium. While humans and other animals build bones from calcium phosphate, many marine organisms make shells by combining calcium with carbonate that forms when CO_2 dissolves in seawater. While students may be familiar with some of the larger examples of these organisms like clam shells and coral, some of the most delicate plankton rely on these chemical reactions (Figure 17). Because they lie at the base of the food chain for many sea creatures, the shells of these delicate organisms are crucial for maintaining ocean ecosystems. Students apply their **models** of chemical equilibrium to predict the impacts of changing CO_2 levels in the ocean on these organisms. There are interactions between CO_2, water, and the shells made out of calcium carbonate ($CaCO_3$) represented by a complex ***system*** of chemical reactions (Figure 18). Each reaction is a dynamic equilibrium with products and reactants constantly being created. Simplifying some of the intermediate reactions, the overall system looks like:

$$CO_2 + H_2O + CaCO_3 \rightleftarrows Ca^{2+} + 2\ H^+ + 2\ CO_3^-.$$

As students apply their **model** of equilibrium reactions from Le Chatelier's principle, they see that as the concentration of CO_2 increases, the ***system*** compensates by producing more products on the right side. The addition of H^+ ions makes the ocean more acidic. The other important ***change*** is that $CaCO_3$ shells dissolve into their constituent ions. Since the beginning of the Industrial Revolution, the concentration of H^+ ions has increased 30%, but projections of future CO_2 emissions by humans may lead to increases up to 150%. The bottom panels of Figure 17 reveal the damage that this increased acidity can have on small and delicate organisms. Students can observe these effects themselves by designing an **investigation** to measure the rate of shell dissolution at different pH levels. Or they can **obtain information** on the health of coral reefs and coral bleaching, due in part to these pH changes.

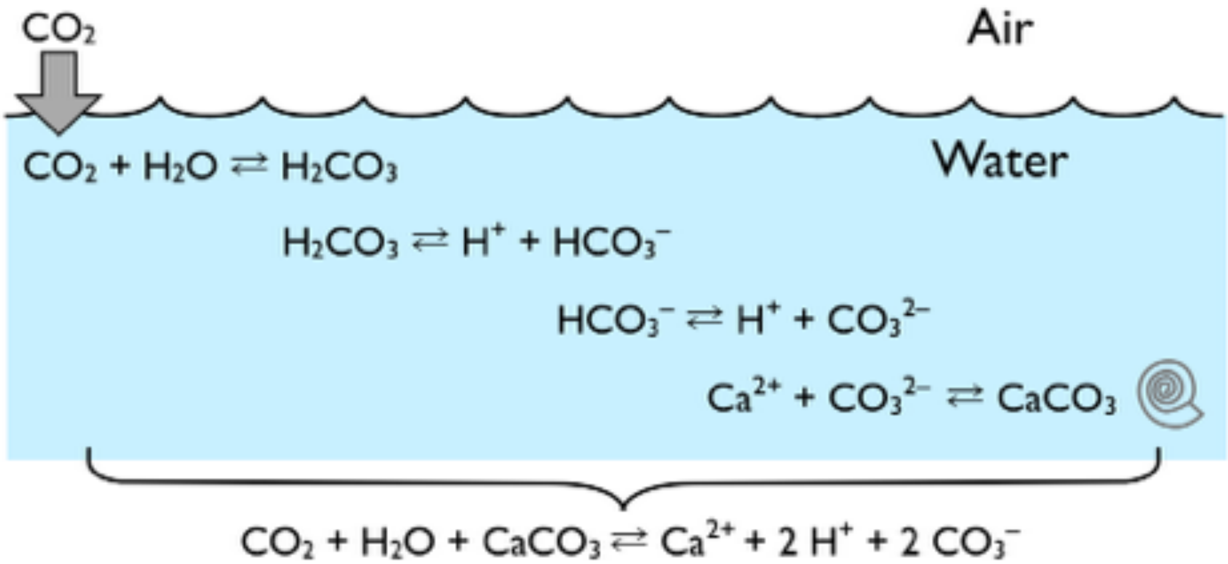
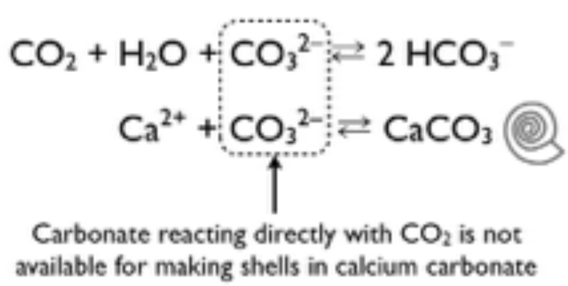


Figure 18. A chain of chemical reactions occur when CO_2 dissolves in ocean water. All of the reactions are equilibrium. The equation on the bottom summarizes the chain to help illustrate how the system changes with an increase in CO_2. Image Credit: (CC-BY-NC-SA) by M. d'Alessio

Shell damage is not the only problem marine organisms face as more CO_2 dissolves in the ocean. The chemistry also makes it harder for them to produce them in the first place. In the engineering task of *HS-PS1-6,* the clarification statement indicates that the design challenge only needs to involve two reactants, but the mental **model** of chemical reactions they develop to meet that PE can be applied to understanding this more complex ***system***. Chemical equations are essentially **models** of these complicated systems, and sometimes different representations of the same ***system*** reveal different features. Using a different combination of the intermediate reactions in Figure 18, the same chemical ***system*** can also be represented by:



This representation indicates that both CO_2 and Ca^{2+} want to react with the carbonate ion, so increasing CO_2 decreases the carbonate available for shell production. (Further inspection of Figure 18 shows that HCO_3^- dissociates to hydrogen and carbonate, and one might think that the carbonate could be used for shell making. While an increase in CO_2 does lead to an increase in carbonate ions, it also leads to an equal increase in hydrogen ions without increasing the concentration of calcium. These hydrogen ions form a tighter, more energetically favorable bond to carbonate than calcium.) Organisms are less likely to encounter carbonate ions that are not already interacting with hydrogen ions, and have trouble building shells. This will result in slower shell production (leaving the organisms vulnerable for a longer time period) or reliance on additional chemical reactions to liberate the carbonate ions from hydrogen (which would require the organism to invest more ***energy*** in shell production, leaving less energy for things like reproduction and evading predators).

High School Vignette

Ocean Acidification: A systems-based approach to a global problem

(adapted from Baliga Lab at Institute for Systems Biology 2010)

Changes in the world's oceans bring together all science and engineering disciplines and are an excellent way to introduce principles of chemical dynamics. While the concentration of CO_2 in our atmosphere is currently 40% higher than it was at the start of the Industrial Revolution, it would be even higher if it were not for the ocean. The ocean constantly exchanges CO_2 with the atmosphere so that the two are in equilibrium. This vignette explores how changes to the ocean's CO_2 concentration disrupt the entire bio-geo-chemical system.

Length and position in course – This vignette describes 2-3 weeks of instruction and could serve as the main instructional segment of instruction for a discussion of chemical equilibrium.

Prior knowledge – This activity has been shown to be more effective when students have existing understanding of systems and systems interactions. A simulation of social networks and cell phones provides an example with which students can easily relate[2].

Day 1-2: Interconnected systems Students analyze news articles to obtain information that documents systems-level interactions between CO ocean chemistry, organisms within the ocean, and human prosperity.	**Days 3-4: Exploring CO** Students conduct a simple engaging activity to visualize the relationship between atmospheric CO and ocean chemistry.	**Day 5: Ocean acidification specifics** Students evaluate information from a movie, noting the way that scientific information is communicated. They identify chains of cause and effect relationships and relate them to Earth's system of systems.
Day 6-9: Planning & Conducting Investigations Different groups of investigate different interactions within the bio-geo-chemical system. They formulate their own research questions and design their own experiment.	**Days 7-9: Online simulations** Students explore complex feedbacks in a computer simulation. They manipulate environmental conditions to see the influence on ocean chemistry and ecosystems.	**Day 10: Summit** Students play the role of different stakeholders. They report the findings of their experiments and use them as evidence to argue for a proposed solution that will reduce the impacts of ocean acidification.

[2] Baliga Lab, Lesson 1: Cell phone network introduction, http://baliga.systemsbiology.net/drupal/education/?q=content/lesson-1-cell-phone-network-introduction

Days 1-2 – Interconnected systems

Ms. K is excited because today her class will begin to document the effects of the chemistry of CO_2 on a huge range of Earth's biological and chemical systems. Ms. K carefully selected a set of articles that illustrates a range of these interactions and assigns a different one to each student along with a sheet with a set of questions. She allows students time to read the articles in class so that she can circulate and help some of the struggling readers. Ms. K has already discussed critical analysis of news stories in her class and asks students to share examples how the author's qualifications and their intended audience affect the tone of the article. Each student must identify key words from the article and create a small network or concept map illustrating the connection between these key words. Students submit their key words to an online form and Ms. K monitors the results as they are submitted. She then pastes the key words into a word cloud generator (where the key words appear in an image with the font size of each word proportional to how often it is used). CO_2 is by far the largest word and a number of other words were utilized multiple times. While the word cloud is good for identifying the common threads, it fails at showing how these common ideas relate to one another. She divides the class up into groups of 4 and gives each group a large sheet of paper. Each group must arrange the submitted key words from the entire class into a single network or concept map. Students snap photos of their maps and upload them to the class webpage. For homework, they will refer to their map and write a short journal article talking about which key concepts and connections they think are most important to investigate, and they brainstorm about how they could investigate such topics.

Days 3-4 – Exploring CO_2

In this activity, students will explore sources and detection of CO_2 in the laboratory. Ms. K reminds students about the evidence that human activities emit CO_2 in the atmosphere. She asks them what their articles from the previous lesson said about how this relates to the ocean water. While the concentration of CO_2 in our atmosphere is currently 40% higher than it was at the start of the Industrial Revolution, it would be even higher if it were not for the ocean. The ocean constantly exchanges CO_2 with the atmosphere so that the two are in equilibrium. As the atmospheric CO_2 goes up, this temporarily disrupts the balance and causes more CO_2 to enter the oceans than leave. Ms. K assigns different students different sources of CO_2 (gas released by a baking soda/vinegar reaction, a combusting candle, dry ice sublimating, and yeast foaming). She tells them to **design an investigation** that simulates an increase in CO_2 in the atmosphere and documents its effect on the pH of the ocean. In order to simulate changes to the atmosphere, Ms. K instructs students that all CO_2 should enter the water through contact with the air (their CO_2 source should not touch the water directly). She does not have access to pH probes, so she gives students droppers of Universal indicator along with flasks, tubing, and other supplies. Students find that the ocean becomes more acidic, which Ms. K explains is the reason that this environmental change is termed 'ocean acidification.'

Ms. K then provides students actual data showing trends in CO_2 concentrations in the ocean and atmosphere as evidence of a balancing feedback between two of Earth's ***systems*** that slows the rate of climate change (*HS-ESS2-2*). The ocean currently absorbs more than a quarter of the annual emissions of CO_2 from human activities. Students can add this fact to their quantitative **model** of the carbon ***cycle*** (*HS-ESS2-6,* ties to instructional segment 5 of the Life Science course). Once they enter the ocean, CO_2 molecules no longer have any impact on the atmospheric greenhouse effect. They do, however, cause significant ***changes*** to the ocean water and life within it (*EP&C Principles II, III, & IV*).

Day 5 – Ocean Acidification Specifics

Students begin by **obtaining information** about ocean acidification by watching a short video. Ms. K has students taking notes about different features of the film. One group records all the statistics in the film while another records facts that are stated but not supported by statistics. All groups track the cause and effect relationships described in the film. After the film, students pair up and discuss the parts of the movie that they found most powerful and the parts that they found weakest. They correlate those reactions with the observations of statistics and other statements not supported by numbers. It varies from group to group whether or not statistics or personal stories were more powerful. While science itself is most powerful when supported by robust quantitative data, **communicating** science requires reaching out to peoples' hearts as well as their minds.

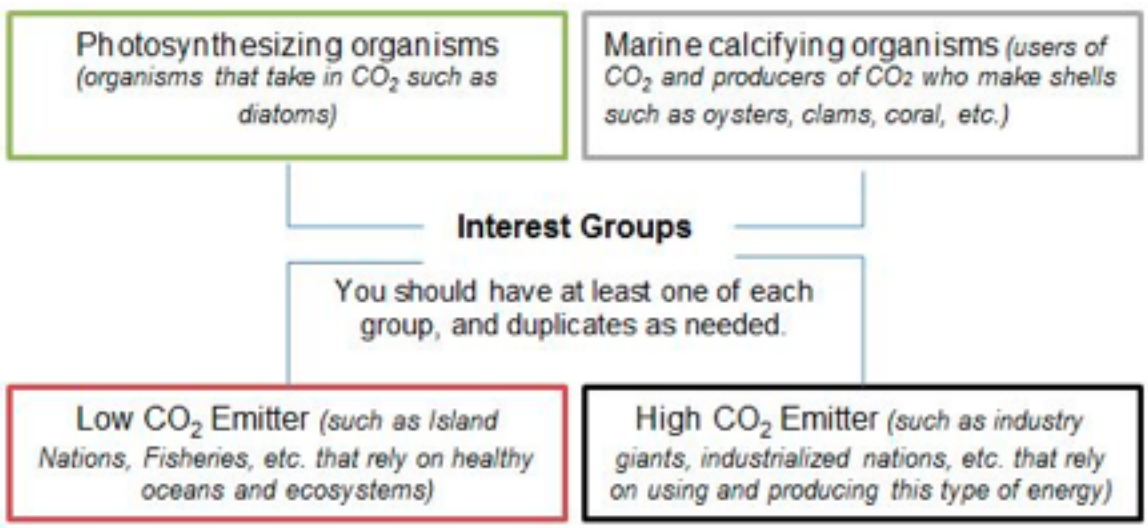
Working in teams, students complete a table summarizing all the ***cause and effect*** relationships mentioned in the movie. They identify which spheres within Earth's systems are involved in each relationship, how CO_2 is involved, and how the change might affect humans. Students then annotate a figure of the carbon cycle circling and labeling how the cause and effect relationships in the movie relate to sections of the carbon cycle. During class discussion, Ms. K asks students to chart chains of cause and effect relationships that involve different spheres in Earth's system of systems. She makes sure that students articulate can articulate the ways in which ocean acidification has large, global causes and that its effects reverberate throughout the system, including our economies.

Ms. K has students make a list of **questions** about the cause and effect relationships they found most interesting. What would they like to find out more about? These questions will form the foundation of student research projects over the next few class sessions.

Day 6-9 – Planning & Conducting Investigations

Ocean acidification involves a huge range of organisms and people. Ms. K tells students that the class will divide up into different interest groups to investigate specific causes, effects, and solutions of ocean acidification. At the end of the instructional segment, the groups will come together for a final summit to present experimental results and provide recommendations for future actions. The main question all interest groups will address is, "What effect does the increasing atmospheric CO_2 have on the ocean and its subsystems?" Each group should focus in one specific effect and plan a detailed laboratory investigation. In other words, they will investigate the interaction between just two or three components of the bigeochemical system. Many of these interactions will be the cause and effect relationships that they recorded while watching the video. Ms. K has a presentation that helps students relate this experiment to systems thinking and gives guidance about refining research questions.

The class will have four main interest groups. Even though all marine organisms are eventually affected by acidification through the food web, two categories of organisms at the base of many food chains are most fundamentally affected: photosynthesizing organisms that take in CO_2 and organisms whose survival depends on making carbonate shells (calcifying organisms). People are related to both the cause and the effects of ocean acidification. Two notable interest groups are those people responsible for most of the CO_2 emissions and those that depend most directly on ocean life for food (such as low CO_2 emitting island nations). Ms. K read through the questions submitted last class period and assigned students to one of four interest groups based on their questions.



(Baliga Lab at Institute for Systems Biology 2013)

With the key goal in mind, Ms. K asks students to list the type of things that they might be able to measure and manipulate in the laboratory in order to gain insight into their interest group's role in ocean acidification. Students will have access to a wide range of materials[3] including living organisms like diatoms called Thaps and brine shrimp (with calcium carbonate shells), sources of carbon dioxide (identical to the investigation from Day X), and tools and supplies to control the environmental conditions of the experimental atmosphere and ocean (including temperature, lighting, salinity, nutrient content of water, etc…). The photosynthesizing organisms group would likely investigate how changes in ocean pH affect their own growth or ways in which changes to their environment could promote their growth to help mitigate rising atmospheric CO_2. The marine calcifying organisms group would likely investigate the effects of a lower pH on their shells or growth. The High CO_2 emitters group would likely investigate ways in which they mitigate their emissions by promoting growth of photosynthesizing organisms or by exploring chemical reactions that capture their CO_2 emissions. They could also experiment by recording the CO_2 emissions of different alternative fuels such as ethanol, natural gas from Bunsen burners, or exploring the efficiency of various renewable energy sources. The Low CO_2 emitters group is most concerned with the impact of acidification on their food supply, so they will likely explore the impacts of CO_2 on one of the different classes of organisms at the base of the food chain. They also might want to explore just how bad ocean acidification could get by testing how far the pH of the ocean can change since it is a buffered solution.

Ms K. walks around to each group, encouraging them to narrow down their investigation to two or three components of the system and asks them to formulate subquestions that their investigation will try to answer. For some groups, she offers a lot of guidance and gives them a menu of ideas they could consider. She helps them deal with logistics, and has a library[4] of background reading and laboratory protocols that she draws from to

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[3] Materials List, http://baliga.systemsbiology.net/drupal/education/sites/baliga.systemsbiology.net.drupal.education/files/L5_OA_TeacherResource-materials.docx

[4] http://baliga.systemsbiology.net/drupal/education/?q=content/lesson-5a-ocean-acidification-experimentation

provide students extra resources. Students will need these to ensure that they can describe the specific chemical reactions occurring in their experiment.

As the groups perform their investigation over the next several days, Ms. K reminds students that their job is to 1) understand the details of their chemical system and be able to relate it to the broader problem of ocean acidification; 2) report their findings at the summit at the end of the session; and 3) Use their findings to inform a solution that can minimize the effects of ocean acidification. To accomplish this last task, they will need to think about how they can manipulate the conditions of the broader chemical system to change the amounts of acid in the ocean (*HS-PS1-6*). Some experiments are quicker, so those groups can proceed to completing online research from the next lesson.

Day 10 – Online research and computer simulations

Ms. K demonstrates a computer simulator that will allow students to explore the overall ***effects*** of ocean acidification on different organisms and actions that people could take to slow acidification[5] (*HS-ESS3-6, HS-LS2-1, HS-ETS1-4, CA EP&Cs II, III*). Students can add CO_2 until the atmospheric concentration matches possible emissions scenarios and examine the impact this will have on different populations of marine life (*HS-ESS3-5*). Students should try to relate the computer simulation to their physical experiment and use data from both to begin to explore possible solutions to ocean acidification.

Day 11 – Summit

Students culminate the instructional segment with a mock summit where they play the part of different stakeholders in the processes contributing to ocean acidification (*CA EP&C V*). Based upon their interest group, they can take up the role of residents of a small fishing village, oil company executives, marine geochemists, tour boat operators

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[5] Institute for Systems Biology, Ocean Acidification: A Systems Approach to a Global Problem – Lesson 5b: http://baliga.systemsbiology.net/drupal/education/?q=content/lesson-5b-online-data-and-supplemental-evidence

at the Great Barrier Reef. To engage in a meaningful **argument**, they will need to **communicate information** about their experiment and its relationship to their character's role (*HS-ETS1-3*). Though each stakeholder makes a contribution to the ***system***, students will need to break apart the problem into pieces and propose solutions that address the components that their character may be able to influence (*HS-ETS1-2*). They should support this proposed solution using evidence from their experiment and the online simulation.

Performance Expectations		
HS-PS1-6 Matter and its Interactions *Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.** ***HS-ESS3-6 Earth and Human Activity*** *Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.* ***HS-LS2-1 Ecosystems: Interactions, Energy, and Dynamics*** *Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.* ***HS-ETS1-4 Engineering Design*** *Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.*		
Science and engineering practices	**Disciplinary core ideas**	**Crosscutting concepts**

Asking questions and defining problems **Planning and carrying out investigations** **Analyzing and interpreting data** **Constructing explanations and designing solutions** **Engaging in argument from evidence** **Obtaining, Evaluating, and Communicating Information**	**PS1.B Chemical Reactions** **ESS3.C: Human Impacts on Earth Systems** **LS2.A Interdependent Relationships in Ecosystems** **ETS1.C: Optimizing the Design Solution**	**Systems and system models** **Cause and effect** **Stability and Change**
Connections to the CA CCSSM: MP.4; A1.N-Q.1; A1.F-LB.1b,c; A1.S-ID.6,7		
Connections to CA CCSS for ELA/Literacy: RST.9-10.2 through RST.9-10.10. SL. 9-10.1b-d, SL.9-10.2 through SL.9-10.6, RST.11-12.2 through RST.11-12.10, SL. 11-12.10.1b-d, SL.11-12.2 through SL.11-12.6		
Connection to CA ELD Standards: ELD.PI.9-10.1.Ex, ELD.PI.9-10.2.Ex, ELD.PI. 9-10.3.Ex		
Connections to the CA EP & Cs: Principle I (Humans depend on natural systems) Principle II (Ecosystems are influenced by human societies) Principle V (Decisions are based on a wide range of considerations)		

Vignette Debrief

Science and engineering practices. CA NGSS Appendix F describes the progression of SEPs through the grade spans. At the end of this high school course, students should be able to demonstrate advanced forms of each SEP. The centerpiece of this vignette is an open-ended investigation that highlights two of SEPs related to experimental design. While students began asking simple questions in kindergarten, this vignette gives them the opportunity **to ask testable questions** about the systems models of ocean acidification that they began to develop on Days 1-2 and 5. In elementary school, they received great guidance with planning simple investigations. They have progressed to the point that on Days 6-9, they **plan an investigation** from scratch where the objective is to revise different interactions in a **model** that will be used to **propose a solution**. The activity culminates by highlighting two SEPs about communicating information and arguments on Day 10 in the Summit. They make and defend claims about the impacts of different human activities and create **arguments** supporting a proposed solution to minimizing these impacts. They support these arguments by **communicating information** about their experimental findings and evidence they **obtained** from background research.

Disciplinary core ideas. The vignette requires application of core ideas in all branches of science where human impacts on one part of Earth's system cause changes to ecosystems in another part due to chemical reactions within a complex bio-geo-chemical system. Engineering and technology are key parts of analyzing the problem and designing solutions. Computer simulations allow students to visualize the impacts of these systems and help them design and evaluate competing solutions to a major problem.

Crosscutting concepts. Ocean acidification is a ***change*** to the equilibrium of a bio-geo-chemical ***system***. By the end of this high school course, students are ready to explore complex interactions within the system that create feedbacks, blurring the line between ***cause and effect***.

California's Environmental Principles and Concepts. Humans depend on ocean ecosystems for food and for its ability to buffer our effects on the carbon cycle (Principle I), while the oceans are clearly impacted by human behavior (Principle II). By assigning students to interest groups and asking them to play the role of different stakeholders, they begin to see the complex interdependencies inherent in a global problem like ocean acidification. In particular, the summit is an excellent example of Principle V that decisions are based on a wide range of considerations from ecological to economic.

Resources for the Vignette

- This activity sequence is based closely on lessons from Baliga Lab at Institute for Systems Biology 2010. Please refer to them for much greater detail: http://baliga.systemsbiology.net/drupal/education/?q=content/ocean-acidification-systems-approach-global-problem. They provide a recorded webinar walking through the lesson sequence and a number of downloadable resources.

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