SciREN Ocean Acidification Lesson Plan

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Introduction/Abstract to Lesson Plan	Increasing atmospheric carbon dioxide (1) increases global temperatures by enhancing the greenhouse effect and (2) dissolves into oceans making seawater more acidic. The lesson's goal is to use these changes in carbon dioxide to ultimately discuss the interconnectedness of all life (including humans) and their physical environments. It will use simple lab-based activities to highlight the scientific method, introduce basic oceanic carbonate chemistry, and explore how changing chemistry affects marine life. The lesson will then guide students to explore how changes in even the smallest marine organisms can impact the ocean ecosystems and human populations that depend on them.
Learning Objectives using Measurable Verbs (what students will be able to do)	Students will use the scientific method to complete an experiment, interpret the results, and formulate hypotheses describing greater impacts of their research. This experiment can then be applied to demonstrate principles of ecology.
Appropriate Grade Levels	9-12 (the basic principles of this lab can be adjusted for many grade levels)
Group Size/# of students activities are designed for	Small groups or full classroom based on resources
Setting (e.g. indoors, outdoors, lab, etc.)	Indoors/classroom lab
Approximate Time of Lesson	~ 60 minutes depending on class/group size and amount of in-class discussion
Resources Needed for Students (e.g. scissors, paper, pencils, glue, etc.)	Tums/Chalk, Soda Water, Tap Water, Small cups to hold water *This experiment has been verified to work with 1000 mg CVS brand Antacid Tablets and Harris Teeter brand Club Soda
Resources Needed for Educators (e.g. blackboard, Powerpoint capabilities, etc.)	Blackboard, projector capabilities can be very useful
Apps/Websites Needed	Optional websites: Have the students calculate their carbon footprint here: http://www.nature.org/greenliving/carboncalculator/ Visual explanation of calcification: http://www.whoi.edu/home/oceanus_images/ries/calcification.html Explanation of CO_2 in seawater: http://www.epoca-project.eu/index.php/restricted-area/documents/doc_download/512-dickson-co2.html
Lesson Activity (step by step description of activity)	Overview i. Introduction to pH

ii. Formulate testable hypotheses to attempt to answer research question
iii. Conduct ocean acidification experiment
iv. Analyze results of experiment
v. Draw parallels between experiment and marine organisms
vi. Make connections between human activities and marine organisms
vii. Investigate solutions to reduce the impacts of ocean acidification

Lesson Plan

a) Discuss the pH scale (0-14). Acids have pH < 7 and bases have pH > 7. In general acids are proton donators and bases are proton acceptors. This means that acids chemically react with bases.

b) Background: Calcium Carbonate is the conjugate *base* of carbonic *acid*.

c) Research Questions: What will happen when Tums/chalk (calcium carbonate: $CaCO_3$) is added to water (H_2O)? What will happen when calcium carbonate ($CaCO_3$) is added to soda water (carbonic acid: H_2CO_3)?

d) Have students generate and record a hypothesis that proposes an answer to each of the research questions. This can be in small groups or as a class.

Using their knowledge of pH, acids, and bases, students may be able to predict that the tums will dissolve in the carbonated water (carbonic acid), but not the non-carbonated water.

e) Students will then conduct their experiment.
Depending on availability of resources and time allotment, the students will conduct the experiment in small groups or as a class. Pour approximately 50-100 mL of soda water into one small beaker/cup and 50-100 mL tap water into a separate small beaker/cup. Add a Tums tablet to the tap water. Students will observe and record what happens for 30 seconds. Add a Tums tablet to the soda water. Students will observe and record what happens for 30 seconds.

f) Students will then discuss the results of their experiment and state whether or not their observations support or do not support the hypotheses they made prior to conducting the experiment.

g) Experiment summary: The tums tablet (calcium carbonate $CaCO_3$) did not dissolve in the water (H_2O), but it did dissolve in the carbonic acid (H_2CO_3). The bubbles are formed when hydrogen ions (H^+) from the carbonic acid (H_2CO_3) react with the calcium carbonate ($CaCO_3$) to form additional carbonic acid (H_2CO_3) that can then decompose into water (H_2O) and carbon dioxide gas (CO_2). These bubbles are carbon dioxide gas that was previously stored as carbonate ($CaCO_3$) and is now released into the atmosphere. This means that carbonate rocks (and other minerals) can effectively store carbon dioxide and remove it from the atmosphere as long as the surrounding chemistry supports it.

h) Experiment background and introduction to ocean acidification:

$$H_2O + CO_2 + CO_3^{2-} \leftrightarrow 2\ HCO_3^-$$

This is a summary equation that simplifies a series of chemical reactions. (See explanation of CO_2 in Seawater website for additional information) [ii]. This simplified equation dictates that water (H_2O) and carbon dioxide (CO_2) react with carbonate ions

(CO_3^{2-}) to form bicarbonate ions (HCO_3^{3}). As a result of this increase in carbon dioxide, there is less carbonate (CO_3^{-}) in the water and more bicarbonate (HCO_3^{-}) in the water. Bicarbonate (HCO_3^{-}) can react with hydrogen ions (H^+) and water (H_2O) to dissociate into hydrogen ions (H^+) and carbonate ions (CO_3^{-}). This production of hydrogen ions (H^+) decreases the pH of the water.

Atmospheric carbon dioxide (CO_2) is increasing primarily due to the combustion of fossil fuels, land use changes, and cement productions. Atmospheric carbon dioxide (CO_2) has increased approximately 40% since the Industrial Revolution (mid 19th-century). As carbon dioxide (CO_2) increases in the atmosphere it is also absorbed into the oceans[i].

To summarize, adding carbon dioxide (CO_2) to seawater can decrease the amount of available carbonate (CO_3^{2-}) in the water and increases the amount of hydrogen ions (H^+) in the water making the water more acidic. This increasing ocean acidity gives rise to the term ocean acidification. Ocean pH has decreased 0.1 pH units since the Industrial Revolution (mid 19th-century) as a result of increasing atmospheric carbon dioxide (CO_2). pH is on a logarithmic scale so this 0.1 pH unit equates to a ~30% increase in hydrogen ions (H^+). Atmospheric carbon dioxide is predicted to reach as high as 900 ppm by the end of the century resulting in a further 0.3-0.4 decrease in seawater pH.

i) A calcifying marine organism is an organism that makes its calcium carbonate ($CaCO_3$) skeleton primarily from calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions in seawater. Based on the their experimental results and the knowledge they've developed thus far, have students predict how increasing atmospheric carbon dioxide could affect calcifying marine organisms.

j) Increasing carbon dioxide in the oceans reacts with water and carbonate (which is important for marine organisms to build their skeletons) to form bicarbonate (which is also a source of carbonate for marine organisms, but organisms must use extra energy to turn this bicarbonate into carbonate to build their skeletons). Therefore, increasing atmospheric carbon dioxide can make it more difficult for some calcifying marine organisms to build their skeletons. This is a great time to show the visual explanation of calcification slideshow.

k) Coccolithophores are phytoplankton with calcium carbonate skeletons and are one of many calcifying organisms that may be vulnerable to ocean acidification. Some examples of other calcifying organisms include crustaceans (shrimp, crab, lobster, etc.), molluscs (clam, conch, etc.), echinoderms (sea urchins, sea stars), and corals. An important concept is that some organisms may be negatively impacted by these changes while others may be positively impacted due to increasing abundances of bicarbonate in seawater.

l) If coccolithophore (phytoplankton) populations are negatively impacted by acidified conditions, have the students hypothesize what will happen to fish populations using the food web.

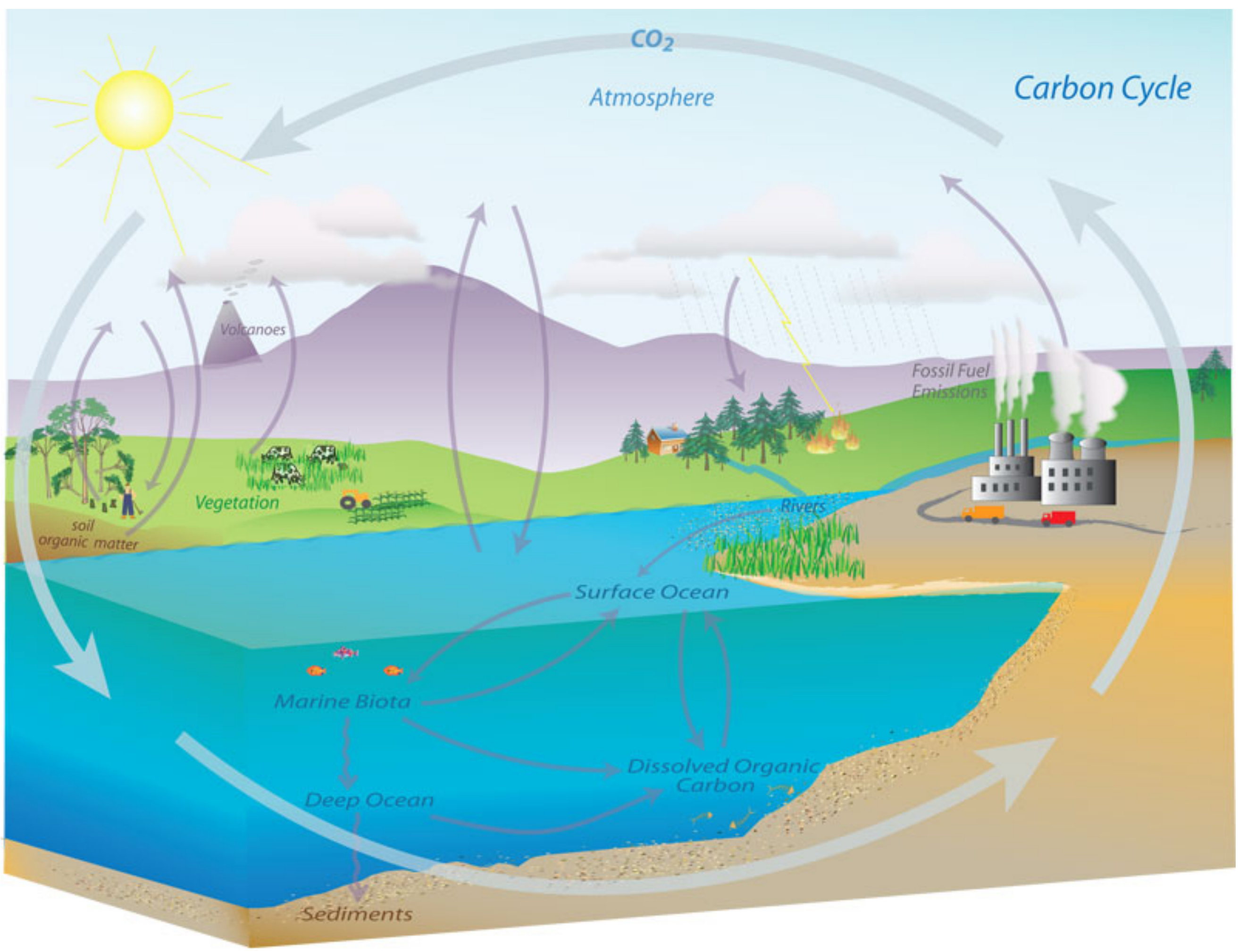
m) According to the WHO, fish, crustaceans, and molluscs account for ~15% of the animal intake by the total human population. Have the students consider how declines in these protein sources resulting from ocean acidification could have an impact on the availability of food we eat.

	n) Summarize with diagrams of the global carbon cycle and ocean food webs. To simplify some potential conclusions: Humans release carbon dioxide into the atmosphere due to the combustion of fossil fuels for energy, land use changes, and cement production. Much (~40%) of this carbon dioxide goes into the oceans and makes seawater more acidic. This acidity can make it more difficult for calcifying marine organisms to build their skeletons. If these organisms are negatively impacted, the human population could lose important sources of protein. o) Have the students hypothesize ways everyone can make a difference. Using what they now understand about ocean chemistry, carbon dioxide, and marine food webs, they can begin to think of ways they can contribute to improve the situation. Some ways include reducing our individual carbon footprints, eating sustainably caught seafood, planting trees, etc. This is a time to be creative and apply what they've learned. Even wild ideas can be a great educational tool if they can explain them using the concepts they've learned. <u>Major themes of this lesson:</u> 1) Humans are having a direct impact on our environment through the release of carbon dioxide. 2) All life is connected to the planet and it's resources. Even the smallest organisms (phytoplankton) are important for ocean life and human food supplies. 3) We can choose to live more sustainably with our planet and conserve the resources we need to thrive for future generations. <u>Some complications of this lesson and room for further teachings:</u> 1) There are ecological winners and losers to ocean acidification. Some organisms will do better while others will do worse. Life is very diverse. This can be linked to natural selection- the organisms best adapted to change will be the most successful in the presence of change. The result is that ecological communities will likely migrate and change through time. 2) Food webs are complicated. Coccolithophores are only one type of phytoplankton. Many other phytoplankton build their skeletons out of silicate. Other phytoplankton may do better or worse with changing ocean chemistry, but are still affected by changing ocean temperatures associated with increasing carbon dioxide. 3) These changes in ocean acidity due to carbon dioxide will also be accompanied by an increase in temperature due to the greenhouse effect of carbon dioxide. Temperature is extremely important when considering the changes that will occur in global ecology due to metabolic rates and organism biogeography. 4) Carbon dioxide is currently increasing at a rapid rate. There have been periods in geologic time where carbon dioxide levels were much higher than they are today. The current trend can be placed in geologic context of changing climate through time. i. This lab can also be used to discuss Henry's Law (the dissolution of gas into liquids). ii. The reaction can also be expanded into a series of reactions utilizing solubility constants. Students can use mathematical theory to predict what will happen or use the equations to explain their observations.
Final Product	This lesson plan can be used as a springboard for a final product. They could hold a debate to find solutions, write blog posts, present their results at a mock scientific conference, etc.

Assessment/Evaluation (Evidence of Learning linked directly to learning objectives)	Students should be able to complete a lab report outlining procedures, results, and conclusions. The students should be able to participate in a group discussion hypothesizing how changes may occur. They could calculate their carbon footprints for homework, and engage in a Socratic seminar the following day discussing how to "solve" this problem.
NC Essential Standards	- Analyze patterns of global climate change over time. - Explain how the lithosphere, hydrosphere, and atmosphere individually and collectively affect the biosphere. - Evaluate human behaviors in terms of how likely they are to ensure the ability to live sustainably on Earth. - Analyze the interdependence of living organisms within their environments. - Understand the impact of human activities on the environment (one generation affects the next).
Next Generation Science Standards	- Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. -Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

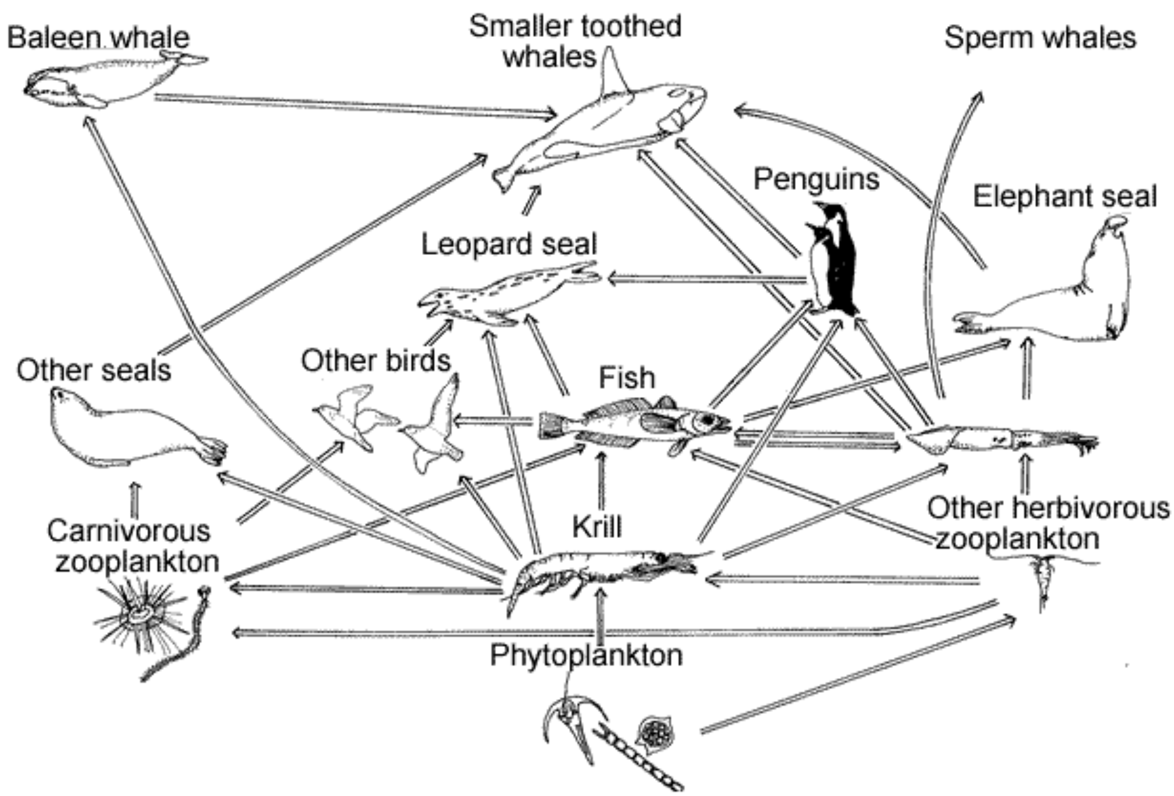
Images

The global carbon cycle:



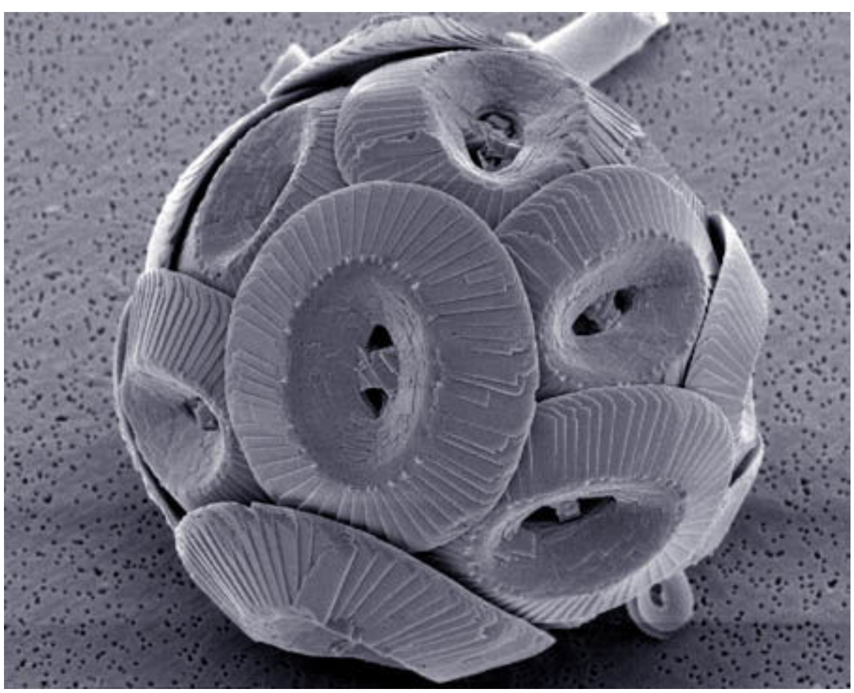
http://www.esrl.noaa.gov/gmd/outreach/carbon_toolkit/images/carbon_cycle.jpg

A simplified ocean food web with phytoplankton at the lowest trophic level:



http://www.coolantarctica.com/Antarctica fact file/wildlife/whales/foodweb.gif

A coccolithophore, the calcifying phytoplankton referenced in this lesson plan:



http://en.wikipedia.org/wiki/File:Coccolithus_pelagicus.jpg