Capstone Advisory Committee Final Capstone Project Signature Form

Stand Up for Science: Lessons on Ocean Acidification
From the Agua Hedionda Lagoon

Shannon Waters

MAS Marine Biodiversity and Conservation
Capstone Project

Capstone Advisory Committee

Signature ___________________ Print Name _______________ Date 9 June 2016
Affiliation Chair __________ Email fwanicz@ucsd.edu Phone 47456

Signature ___________________ Print Name _______________ Date 10/9/16
Affiliation EOS __________ Email rmillstone@ucsd.edu Phone (858) 822-3589
STAND-UP FOR SCIENCE:
LESSONS ON OCEAN ACIDIFICATION FROM THE AGUA HEDIONDA LAGOON

SHANNON WATERS | MAS-MBC PROGRAM
SCRIPPS INSTITUTION OF OCEANOGRAPHY

Advisors:
Dr. Todd Martz (Chair), UCSD, Scripps Institution of Oceanography
Dr. Rachel Millstone, Ed.D, UCSD, Department of Education Studies
# TABLE OF CONTENTS

## INTRODUCTION  
- Ocean Acidification & Ocean Literacy  2  
- Goals of this Project  2  
- The WaveHOx  3  
- Next Generation Science Standards (NGSS)  6  
- Agua Hedionda Lagoon  6

## METHODS  
- Developing Lesson Plans  7  
- Planning & Delivering Workshops  12  
- Documenting the Workshops  12

## RESULTS  
12

## DISCUSSION  
13

## REFERENCES  
15

## APPENDIX  
- A. Workshop Flyer  16  
- B. Lesson Plans  17  
- C. Workshop Evaluation Responses  72  
- D. Slideshow – Climate Change & Ocean Acidification Overview  92
INTRODUCTION

Ocean Acidification & Ocean Literacy
Climate science has been a hallmark discipline at Scripps Institution of Oceanography (SIO) since at least 1958 when Scripps researcher Charles David Keeling began taking measurements of atmospheric carbon dioxide from the Mauna Loa Observatory in Hawaii. Since then, climate science has become a firmly rooted discipline of study at SIO, as evidenced by the numerous publications by SIO scientists advancing this body of research and the newly minted Center for Climate Change Impacts and Adaptation. It is not surprising, therefore, that some of the first research to note the affects that climate change has on our oceans came from SIO scientists as well. Current research at SIO includes the study of ocean acidification and climate change on biology like corals, crustaceans, and deep-sea species, the development of chemical sensors to measure and monitor ocean acidification, and a look back in time at paleoceanography and the changes of climate and the chemistry of our oceans over geological time.

However, despite the wide body of knowledge about ocean acidification that exists within the scientific community, people outside the scientific community are woefully unaware of the issue of ocean acidification. In a 2010 study conducted by Yale School of Forestry, only 25% of respondents to a national survey had ever heard of coral bleaching or ocean acidification (Leiserowitz et al). This lack of understanding isn’t limited to these two topics alone, but highlights a larger lack of understanding of the importance the ocean plays in our lives in general. A 2009 national study conducted by The Ocean Project revealed that 35% of survey respondents could not identify a single ocean-related issue affecting the U.S. Of those who could identify an issue, many could not elaborate beyond statements such as, “we cannot live without water“ and “we need fish to survive” (The Ocean Project, 2009). This same study also found that ocean literacy rates have not improved over the ten years when The Ocean Project first began market research on ocean literacy in 1999.

One group of individuals does stand out in their interest and engagement in ocean issues: teenagers. In a 2011 annual update called America and the Ocean, The Ocean Project found that teens have the highest level of concern about ocean health, and are the most confident in their ability to make a difference (The Ocean Project, 2011). The same study also found that teens are increasingly asked for advice on environmental topics by the adults in their families. Engaging teens in marine science education programs is therefore critical to advancing ocean literacy within society at large in order to develop conservation solutions to address declining ocean health.

Goals of this Project
The goal of my capstone project was to develop one such program. Using the body of expert knowledge and resources at SIO, I developed a unit of curriculum based on ocean acidification that can be used in the high school classroom. Each of the four lesson plans connects the student to an area of historical or active research at SIO and introduces them to the scientific methods and technology used to advance research. I delivered these lesson plans to middle and high school science teachers in a two-day workshop held at the Birch Aquarium. In addition, I invited SIO scientists to attend to present on their area of research. Dr. Todd Martz, Associate Professor with the Geosciences Research Division at SIO presented on the marine chemical sensors developed in his lab, including the WavepH0x. Dr. Maya deVries, a post-doc in the Taylor Lab, presented on her active research on ocean acidification impacts on mantis shrimp (Neogonodactylus bredini). The teachers spent the two days in the classroom learning methods for teaching their students about ocean acidification and the science behind the lessons. In addition, we spent an afternoon in the field learning about the technology behind the WavepH0x and how it collects data on marine chemistry.
The WavepHOx
The WavepHOx (Figure 1) is an autonomous chemical sensor developed in Todd Martz’ lab at Scripps Institution of Oceanography. It is a relatively small instrument, measuring 22 inches long by 6.5 inches wide, and 3.25 inches high. It weighs about 10 pounds.

Figure 1. The WavepHOx

The WavepHOx uses a Honeywell Durafet pH sensor to measure pH, an Aanderaa optode oxygen sensor to measure oxygen, and a conductivity probe used to measure salinity (Bresnahan et al 2016). Both the Durafet and the optode oxygen sensor are outfitted with a thermistor to measure temperature. It represents the newest model in a series of chemical sensors developed in the Martz lab, following an autonomous sensor package called the SeapHox, which measures the same properties. The primary difference between the WavepHOx and SeapHox is the shape of the housing. The WavepHOx is streamlined to attach to the bottom of a stand-up paddleboard (Figure 2) or other mobile device. In this way, the WavepHOx can be used to map surface pH, oxygen, temperature and salinity over a wider range geographically than other similar chemical sensors. It is especially useful in accessing the near-shore environment like the surf-zone, bays, and lagoons, as well as in environmentally sensitive habitat regions like sea-grass beds where minimal impact is paramount. The data collected with the WavepHOx – pH, oxygen, temperature, and salinity levels of a body of water – can inform us of the chemical changes that occur over the course of a day, like photosynthesis and respiration, or can inform us to more long-term changes in marine chemistry, like ocean acidification.
Figure 2. WavepHOx deployed on a stand-up paddleboard

Image Credit: Shannon Waters
Previous Research Using the WavepHOx

The WavepHOx is a relatively new instrument but has already proved to be a valuable tool for measuring marine chemistry. As a PhD candidate in the Martz lab, Phil Bresnahan deployed the WavepHOx several times over the period from November 2014 to June 2015 to measure the chemical properties at three locations: La Jolla Shores, Mission Bay, and the open ocean directly west of Scripps Pier (Bresnahan et al., 2016). The deployments at La Jolla Shores and Mission Bay were conducted via stand-up paddleboard. The deployment west of Scripps Pier was conducted on a wave-glider built by Liquid Robotics (Figure 3).

Outreach with The WavepHOx

While the primary focus of the work by Bresnahan et al (2016) was the development of chemical sensors, the authors also recognized the power of the WavepHOx as an outreach tool. The Mission Bay deployment was done in partnership with the Andersson Lab at SIO and Ocean Discovery Institute on a twenty-four hour over-night field trip with about 30 middle school students. The students helped collect data and later visited the Andersson Lab to learn about carbon chemistry. In addition, Dr. Bresnahan brought the WavepHOx into classrooms for presentations, attended public science fairs and a surf fair called The Boardroom, and was even interviewed by the local news.

I first learned of the WavepHOx and the outreach Phil Bresnahan had conducted during a presentation he gave to the new MAS-MBC students in 2015. I was immediately drawn to the WavepHOx as a way to engage people in marine chemistry and wanted to build upon the outreach projects initiated by Phil. I began exploring the possibility of developing a citizen science project whereby I could bring a group of students onto the water and deploy multiple WavepHOx sensors simultaneously. However, after investigating that idea further, I learned that limited availability (currently 3 prototypes) and cost of a single WavepHOx ($16k) would prohibit its use by large groups at the present time. The high cost and limited supply meant that I would have to create another way to bring the science and technology of the WavepHOx to a wider audience.

I decided that if I couldn’t bring students onto the water to witness the WavepHOx in action, I would bring the WavepHOx and the science behind it into their classroom. To do this, I would develop a series of lesson plans, based on the WavepHOx and marine chemistry to teach high school students about ocean acidification, based on current research being done at Scripps and using real data sets collected by the WavepHOx and other chemical sensors.
**Next Generation Science Standards**

In order for my lesson plans to be of use to classroom teachers, I needed to ensure they were addressing the standards for the high school grade level. Education standards are the core learning objectives that each student should understand at the end of their academic year. They lay the blueprint for teaching and learning for each grade level. In California, these standards are periodically reviewed and updated to incorporate the newest understanding and research in pedagogy and learning, and to prepare students for the opportunities and markets of employment that lay ahead after graduation. The last significant revision of California’s education standards was in 1998. These standards however have fallen short of the preparation students need to be competitive in today’s economy. A series of recent studies on the U.S. education system found that U.S. graduates fall behind their counterparts from other countries in math and science. The 2012 Program for International Student Assessment (PISA) ranks the United States as 23rd in Science, 30th in Math, and 20th in Reading Literacy out of the 65 OECD (Organization for Economic Cooperation and Development) education systems (Kelly et al, 2013). At the same time, the markets are shifting so that hires are expected to have strong math and science skills. As such U.S. graduates are becoming less competitive in the workforce. Outside of employment, students must be prepared to participate as an educated member of society. As citizens we are asked to evaluate claims and policies on issues like health care, climate change, and tax policies. In order to make informed decisions, we as citizens need the math and science skills to evaluate these policies from an informed perspective.

To address these concerns, in 2013, California adopted a new set of standards for science called the Next Generation Science Standards, or NGSS. These new standards still maintain that students understand core concepts (laid out in specific terms as Performance Expectations and Disciplinary Core Ideas), however also emphasize that students understand how science is performed by teaching students how to do it (Practices) and highlight themes that recur throughout each grade level (Crosscutting Concepts). In this way, NGSS emphasizes the importance of learning through inquiry, investigation, exploration, and experimentation. All this lends itself to a richer learning experience through NGSS.

**Agua Hedionda Lagoon**

The Agua Hedionda Lagoon is located in Carlsbad, CA. It is situated at the end of the Agua Hedionda watershed, which drains from the cities of Carlsbad, Oceanside, Vista, San Marcos, and unincorporated County of San Diego.

We chose this as our study site for two reasons: first, there is already a history of data collected through various other studies at the Lagoon, including a shore station chemical sensor located in the southwest portion of the lagoon and a coastal wetland study underway by Scripps researcher Sarah Giddings. By doing research with the WavepHox here, we are adding to the existing body of research. Second, the Lagoon features both natural and manmade features that are related to the subject of ocean acidification and as such, the lagoon itself can be a learning tool for students. For example, the I-5 freeway intersects the lagoon, and the cars driving on it directly contribute to the increase of carbon dioxide in the Earth’s atmosphere. Second, the Carlsbad Aquafarm, which harvests oysters and mussels, calcium carbonate-building organisms, is located in the southwest area of the lagoon. Oysters and other calcium carbonate-building organisms are already feeling the effects of more acidic ocean conditions, especially in the Northwest. The features of the lagoon therefore can be jumping off points to teach students about global implications of ocean acidification.
METHODS
After becoming familiar with the WavepHOx technology, the Next Generation Science Standards, and identifying a study site, I set about developing lesson plans that incorporated the central concepts connected to ocean acidification. By examining the performance expectations for different grade levels, I had previously identified high school students as the target audience, and since the subject of ocean acidification requires that students have some background knowledge of basic chemistry and biology, I designed the lesson plans for a high school marine biology or advanced placement (AP) environmental science class.

Developing Lesson Plans
My first step in developing lesson plans was to identify which performance objectives I could address through the activities I developed. Doing that was more challenging than I expected, as it’s a bit of a “chicken or the egg” process. After identifying which performance expectations my lesson plans could address, it wasn’t until the lessons were complete that I could confidently say my activities did address them, and some lessons needed to be reworked before they truly addressed the intended performance expectation. In the end, the lessons I developed addressed these performance expectations:

- HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. (Lesson #2: Ocean Acidification; Lesson #3: OA Impacts on Oysters & Mantis Shrimp)
- HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity. (Lesson #3: OA Impact on Oysters)
- HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts on Earth systems. (Lesson #1: Keeling’s Curve – The Story of CO2) (Lesson #4: How We Collect Data: the WavepHOx & Calculating pH - builds towards this PE by addressing the DCI ESS3.D: Global Climate Change)
- HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts. (Performance Task)
In addition, the unit addressed these NGSS Dimensions:

**NGSS Disciplinary Core Ideas (DCI)**

**LS2.C: Ecosystem Dynamics, Functioning, and Resilience**
- A complex set of interaction within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e. the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.
- Moreover, anthropogenic changes (induced by human activity) in the environment – including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change – can disrupt an ecosystem and threaten the survival of some species.

**ESS3.C: Human Impacts on Earth Systems**
- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.

**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.

**EST1.B: Developing Possible Solutions**
- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.

**ETS1.C: Optimizing the Design Solution**
- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.
To develop each activity, I spent some time brainstorming about the topic and the best way to explain it within the NGSS framework. In addition, I looked to existing activities and lesson plans already created that could be adapted for this unit specifically. Each of the four lesson plans are detailed below.

**Lesson #1: Keeling’s Curve – The Story of CO2**

The first lesson introduces students to the subject of climate change and the Keeling Curve. To prepare teachers for this lesson, I also created a slideshow on climate change that teachers can use to inform themselves, and teach to their students. The slideshow is included in the appendix. In the first lesson, students watch a brief video created by the American Museum of Natural History called “Keeling’s Curve – The Story of CO2” and work in a small group to answer analysis questions. Through these activities, students learn that Charles David Keeling was a researcher at Scripps Institution of Oceanography who measured levels of carbon dioxide in the Earth’s atmosphere. His measurements initially showed seasonal variations, however over time carbon dioxide levels have increased dramatically. When he began his measurements in 1958, carbon atmospheric carbon dioxide levels stood at around 315 parts per million (ppm). Today, they have increased to just over 407 ppm (as of May 26, 2016; Scripps Institution of Oceanography, 2016). Students also learn that our ocean absorbs around 25% of atmospheric carbon dioxide, and that when carbon dioxide combines with seawater, carbonic acid is
formed, altering the pH of the ocean at the surface (Figure 4). This process is known as ocean acidification.

**Figure 4: The Keeling Curve with Seawater pCO2 and pH Plotted**

Lastly, students conduct an experiment (adapted from BIOACID, 2012) to visualize this change in pH by trapping carbon dioxide inside a closed glass container that is filled with a solution of water and pH indicator dye. This lesson addresses the NGSS performance expectation HS-ESS3-5, which is to “Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts on Earth systems.” (NGSS, 2013)

**Lesson #2: Ocean Acidification**

The second lesson delves deeper into the topic of ocean acidification. Students work in teams to complete questions from a reading titled, “What is Ocean Acidification?” from an article published by Woods Hole Oceanographic Institution (WHOI). Through the reading, students learn several important concepts. First, that carbon dioxide in Earth’s atmosphere is absorbed by the ocean (reinforcing this fact learned in Lesson #1), and that seawater pH decreases as the ocean takes up more carbon dioxide, a process known as ocean acidification. Second, students learn that scientists can determine what carbon dioxide levels in the atmosphere and in the ocean were thousands of years ago by looking at proxies like shell fossils found in sediment or ice core samples. Third, students learn that although the Earth has experienced a large release of carbon dioxide before (during the Paleocene-Eocene era), it happened over thousands of years giving species time to adapt, and it is the faster rate of change we’re experiencing today that could cause irreversible change to today’s ocean ecosystems. Lastly, students learn that the organisms most at risk from ocean acidification are marine calcifiers. These organisms, like planktonic pteropods, mussels, oysters, and corals face two threats from ocean acidification. First, as ocean pH becomes more acidic, their shells are more easily dissolved. Second, the carbonate ions needed to build their calcium carbonate shells is less available, making it difficult to build their shells in the first place, especially in larval stages. Finally students work together to build a concept map in which they make connections between the terms and concepts they just learned. As a learning tool, a concept map forces students to not only understand each concept, but how each is connected to the others. It reinforces systems thinking. This
Lesson #3: Ocean Acidification Impacts on Oysters and Mantis Shrimp

After learning about ocean acidification and its causes, students are ready to delve into the impacts ocean acidification will have on various organisms in the ocean. In the reading from Lesson #2, students read that ocean acidification could negatively affect marine calcifiers like oysters. In Lesson #3, they perform an experiment (adapted from NOAA National Marine Sanctuaries, 2015) and witness the dissolution process take place. In this activity, students take clean oyster shells and measure their weight. Next they place the shells into glass jars filled with seawater. Student use a bike pump to carbonate the water in each of the jars to varying pH levels, trying to obtain a range of pH levels between 5 to 7.8 pH. The average pH level of seawater is currently about 8.1, and it is very unlikely the ocean will ever become as acidic as 5 pH, however the more acidic water demonstrates a faster rate of dissolution that can otherwise only be seen over a longer period of time than that allowed in the classroom. After carbonating each jar, leaving one as a control, students record the pH of each jar, seal off each jar with a tight-fitting lid, and set the jars aside for a week. After the week has passed, students open the jars and dry the shells overnight. Once the shells are dry, they record the mass once again and graph their results. Lastly, students consider what actions they could take to reverse the pH level to make a more alkaline solution and test their ideas. This experiment demonstrates how acidic conditions weaken the shells of oysters and other calcium carbonate shelled organisms. This activity addresses performance expectation HS-LS2-6 which states, “evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem,” and performance expectation HS-LS4-6, which states, “create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.”

However, not all organisms will be affected equally by ocean acidification. The next activity, which was created and delivered by Dr. Maya deVries, a post-doc in the Taylor lab, demonstrates this through her research on mantis shrimp. The lesson begins with background on the biology, diet, and physiology of the mantis shrimp. Students learn that the mantis shrimp has a raptorial appendage that it uses to smash their prey. This strike is one of the fastest movements in the animal kingdom! It’s so fast that if a mantis shrimp of human size were to throw a baseball, it would send the baseball into orbit around the Earth. This appendage and the strike are closely tied to the mantis shrimp exoskeleton and students are asked to hypothesize about how mantis shrimp and their exoskeleton will be affected under ocean acidification. In the end, students learn the details and results of Maya’s study which show that even in more acidic and high temperature conditions the mantis shrimp is largely unaffected by ocean acidification. By demonstrating these lessons back to back, students learn that ocean acidification affects different species in different ways. This lesson further reinforces performance expectation HS-LS2-6 which states, “evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.”

Lesson #4: How We Collect Data: The WavepHOx and Calculating pH

The last lesson introduces students to some of the sensors used to measure marine chemistry. It begins with a video created for this unit that introduces the WavepHOx. Featured in the video are the teachers who participated in the workshops. Students are probably familiar with traditional instruments used in science, however have probably never heard of an instrument that allows researchers to collect data from a stand-up paddleboard. Students are presented with data collected with the WavepHOx and analyze the maps that show pH, oxygen, and temperature over three time periods taken on the same day.
at 6:00AM, 8:00AM, and 10:00AM. Through the lesson, students learn how daily processes, like photosynthesis and respiration, also contribute to the marine chemistry. Lastly, students learn how to access and analyze live data from a shore sensor located in the Agua Hedionda Lagoon. The activities in this lesson build towards performance expectation HS-ESS3-5, which is to “analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems” by addressing Disciplinary Core Idea ESS3.D: Global Climate Change, which reads, “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.”

Planning & Delivering Workshops
I delivered these lesson plans to participating middle and high school teachers at two training workshops held on May 7th and May 14th from 10AM to 4PM at the Birch Aquarium. Workshop participants spent the first half of the day on May 7th in the classroom learning about climate change, ocean acidification, and the WavepHOx. Dr. Todd Martz presented about the research conducted in his lab with the WavepHOx and other chemical sensors, and how his research fits into the larger history of climate science research at Scripps. The afternoon of the first day was spent on the water to give the teachers a tour of the Agua Hedionda Lagoon and the experience of doing fieldwork with the WavepHOx.

The second day of the workshop was held a week later on May 14th. The entire day was held in the classroom exploring each of the lesson plans in detail. I chose select activities to demonstrate, including the ocean acidification experiment from Lesson #1, the concept map from Lesson #2, the oyster shell dissolution activity from Lesson #3, and both of the activities interpreting data from Lesson #4. Dr. Maya deVries also joined us to present about her research on the affect ocean acidification has on mantis shrimp.

Documenting the Workshops
I invited documentary filmmaker Cynthia Matzke to attend both days on the workshop to film and interview workshop attendees. Cynthia also accompanied for the fieldwork at Agua Hedionda Lagoon and conducted several other interviews with scientists at Scripps who are researching ocean acidification in some way. This footage will be made into a video that workshop participants can use in their classroom to inform their students about the WavepHOx and ocean acidification.

RESULTS
Each workshop participant was asked to fill out a post-workshop evaluation. The written and verbal feedback was overwhelmingly positive. In addition, I asked teachers to answer questions to gauge how important it was to them to provide their students with activities that bring active research topics and live data sets into the classroom. Below is a summary of the evaluation questions (n = 10). The evaluation responses and comments are included in the appendix.

Question #1: As a result of participating in this workshop, I feel informed about climate change and ocean acidification.
- Strongly Disagree: 0
- Disagree: 0
- Neutral: 0
- Agree: 3
- Strongly Agree: 7
Question #2: As a result of participating in this workshop, I feel prepared to teach my students about climate change and ocean acidification.

- Strongly Disagree: 0
- Disagree: 0
- Neutral: 0
- Agree: 5
- Strongly Agree: 5

Question #3: The experiments and activities conducted in this workshop will help my students conceptualize the chemical changes that result from ocean acidification.

- Strongly Disagree: 0
- Disagree: 0
- Neutral: 0
- Agree: 0
- Strongly Agree: 10

Question #4: It is important to me that my students have access to data sets that are the result of active and on-going research.

- Strongly Disagree: 0
- Disagree: 0
- Neutral: 0
- Agree: 0
- Strongly Agree: 10

Question #5: Teaching my students about the WavepHOx and other novel ways to conduct research will get them excited about science.

- Strongly Disagree: 0
- Disagree: 0
- Neutral: 0
- Agree: 4
- Strongly Agree: 5
- No response: 1

Question #6: Overall, I would rate this workshop...

- Terrible: 0
- Bad: 0
- OK: 0
- Good: 0
- Awesome: 8
- No response: 2

DISCUSSION
As California schools are transitioning to incorporate the Next Generation Science Standards, resources that bring science alive for their students in ways that promote inquiry, investigation, experimentation, and exploration will be incredibly valuable. At the same time, funders for scientific research like National Science Foundation (NSF) are requiring that researchers find ways that their research can have a broader impact beyond the scientific community. The unit of curriculum and workshop I developed is one example of how both goals can be achieved.
Looking ahead, I will want to keep in contact with the teachers who participated in the workshop to learn how they incorporate the lessons I developed into their classrooms and how their students responded to the activities. Ultimately I would like to track whether these engaging lessons encourage students to pursue careers in science, although tracking this kind of long-term causal relationship poses its own challenges.

Ideally, the WavepHOx will continue to be used as an outreach tool as well (perhaps as a capstone project for one of next year's MAS-MBC students). During the time I've spent developing my capstone project, nearly everyone I've spoken to about the WavepHOx has asked how he or she could participate. With enough funding, perhaps a low-cost version could become available that could develop into a citizen science project.
REFERENCES

BIOACID (2012). The Other CO2 Problem: Ocean Acidification. Experiment #2 pg. 54-55. www.bioacid.de


STAND-UP FOR SCIENCE:
LESSONS ON OCEAN ACIDIFICATION FROM
THE AGUA HEDIONDA LAGOON
A TWO-DAY WORKSHOP FOR HIGH SCHOOL SCIENCE TEACHERS

SATURDAY, MAY 7TH 10AM-4PM
SATURDAY, MAY 14TH 10AM-4PM
Birch Aquarium
2300 Expedition Way, La Jolla, CA 92037

Researchers at Scripps Institution of Oceanography are developing new ways to study marine chemistry, ocean acidification, and human impacts on marine ecosystems. The Martz lab has developed the WavepHox, a stand-up-paddleboard (SUP) equipped with a pH and oxygen sensor. This SUP is being used to study marine chemistry in the Agua Hedionda Lagoon. Conducting research while paddleboarding? Yes! It’s SUP Science! Come learn about the WavepHox and get a chance to ride it yourself at this ocean acidification workshop for high school science teachers. Participants will be guided through an NGSS-aligned unit of curriculum developed by Shannon Waters, a graduate student at Scripps Center for Marine Biodiversity and Conservation.

Participating teachers will receive:
• An NGSS-aligned, inquiry-based unit of curriculum that uses authentic scientific data and technology to address basic ocean chemistry and human impacts (e.g. climate change and ocean acidification)
• A chance to ride on the WavepHox, guided by researchers at Scripps
• A $50 stipend and a certificate recognizing your participation
• The option to be featured in a WavepHox film to use in your classroom
• Lunch will be provided!

Register for the workshop here. Space limited to 10 teachers.
Stand-Up for Science:
Lessons on Ocean Acidification from the Agua Hedionda Lagoon

Created by
Shannon Waters
Candidate, Masters of Marine Biodiversity and Conservation
Scripps Institution of Oceanography
In this unit of curriculum, students will explore the science and processes that govern global climate change and ocean acidification (OA). The unit was developed to incorporate research at the Agua Hedionda Lagoon in Carlsbad, CA where scientists from Scripps Institution of Oceanography are using chemical sensors, like the WavepHOx, to measure and monitor the carbon dioxide profile of the lagoon. The WavepHOx is an instrument that measures pH, oxygen, and temperature and is attached to a stand-up paddleboard, allowing researcher to map the chemical ebbs and flows of the lagoon (Lesson #4). Seawater chemistry changes when the composition of gases in the atmosphere changes, so understanding the ocean chemistry aids researchers in understanding climate change.

In this unit, your students will learn about climate change, the Keeling Curve, the chemistry behind ocean acidification, and the impacts ocean acidification has on plankton, oysters, and mantis shrimp. Students will be introduced to the WavepHOx and will learn how to access and interpret live data sets. As a final performance task, students demonstrate their understanding of these concepts through a role-play debate in which they argue the merits of a hypothetical coal-fired power plant development project near the Agua Hedionda Lagoon.

The goal of this curriculum is to bring the active and on-going research at Scripps Institution of Oceanography into the high school classroom. This unit was developed in alignment with the Next Generation Science Standards. It is intended for a high school marine science or environmental studies class, and it is assumed students have some background knowledge of basic chemistry and biology.

The process of developing this unit would not have been possible without the following individuals and I thank them for giving so graciously of their time, their expertise, and their guidance.

**Capstone Committee Members**
Todd Martz, Chair (Scripps Institution of Oceanography)
Rachel Millstone (University of California San Diego)

**Workshop Attendees**
Bridget Altman (Scripps Institution of Oceanography)
Lorrie Blackard-Freit (UCSD/Sally Ride Foundation)
Jacqualine Chan (University of California, San Diego)
Maya deVries (Scripps Institution of Oceanography)
Cynthia Matzke (Scripps Institution of Oceanography alum/Sally Ride Foundation)
Chris Olivas (High Tech High)
Autumn Ross (Patrick Henry High School)
Kent Sargent (Hilltop Middle School)
Leah Silverman (Patrick Henry High School)
Steve Walters (Mission Bay High School)
Ann Wegmann (Patrick Henry High School)

**Advisors**
Bonnie Drolet, Ed.D (Former Assistant Superintendent, Encinitas School District)
Ron Wells (Retired, Middle and High School Science Teacher, San Diego Schools)
NGSS Performance Expectations Addressed in this Unit:

<table>
<thead>
<tr>
<th>NGSS Performance Expectations</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. (Lesson #2: Ocean Acidification; Lesson #3: OA Impacts on Oysters &amp; Mantis Shrimp)</td>
</tr>
<tr>
<td>HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity. (Lesson #3: OA Impact on Oysters)</td>
</tr>
<tr>
<td>HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts on Earth systems. (Lesson #1: Keeling’s Curve – The Story of CO₂) (Lesson #4: How We Collect Data: the WavepHOx &amp; Calculating pH - builds towards this PE by addressing the DCI ESS3.D: Global Climate Change)</td>
</tr>
<tr>
<td>HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts. (Performance Task)</td>
</tr>
</tbody>
</table>

NGSS Dimensions Addressed:

<table>
<thead>
<tr>
<th>NGSS Disciplinary Core Ideas (DCI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LS2.C: Ecosystem Dynamics, Functioning, and Resilience</strong></td>
</tr>
<tr>
<td>• A complex set of interaction within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e. the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability</td>
</tr>
<tr>
<td>• Moreover, anthropogenic changes (induced by human activity) in the environment – including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change – can disrupt an ecosystem and threaten the survival of some species.</td>
</tr>
<tr>
<td><strong>ESS3.C: Human Impacts on Earth Systems</strong></td>
</tr>
<tr>
<td>• Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.</td>
</tr>
<tr>
<td><strong>ESS3.D: Global Climate Change</strong></td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td><strong>ETS1.B: Developing Possible Solutions</strong></td>
</tr>
<tr>
<td>• When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.</td>
</tr>
<tr>
<td><strong>ETS1.C: Optimizing the Design Solution</strong></td>
</tr>
<tr>
<td>• Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.</td>
</tr>
</tbody>
</table>
### Science and Engineering Practices

**Constructing Explanations and Designing Solutions**
- Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

**Engaging in Argument from Evidence**
- Evaluate the claims, evidence, and reasoning behind currently accepted explanations of solutions to determine the merits of arguments.

-------------

### Connections to Nature of Science

**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.
- New technologies advance scientific knowledge.

**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.

### Crosscutting Concepts

**Stability and Change**
- Much of science deals with constructing explanations of how things change and how they remain stable.
- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.
- Feedback (negative or positive) can stabilize or destabilize a system.

**Cause and Effect**
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
Performance Task

Performance Expectation Addressed:
HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Description of Performance Task

Upon completion of the lesson plans included in this unit, students will have a foundational understanding of climate change and ocean acidification and will be ready to evaluate ideas and proposals that would directly or indirectly influence the chemical properties of the Agua Hedionda Lagoon and the marine organisms that live there. To demonstrate their knowledge, students evaluate a (hypothetical) proposal to build a coal-fired power plant at the Agua Hedionda Lagoon.

Background: The price of buying a home in San Diego County is increasing, and the City Council Members in Carlsbad have been under pressure to approve low-cost housing near the Agua Hedionda Lagoon where the Strawberry Fields now sit (map). The housing development project was approved, and construction will begin within the next couple of months. These homes will need energy to power them though, and so - to keep costs low to homeowners – Coal-4-U power suppliers has proposed to build a coal-fired power plant nearby (coal is the cheapest fossil fuel, but also the biggest polluter of carbon dioxide; teachers note: you can either provide that information about coal or assign that research as part of the assignment). The City Council must vote on a decision to approve or deny the proposal from Coal-4-U after hearing from all the stakeholders.

Students are assigned roles based on the various stakeholders involved. Stakeholders include:
- A person interested in buying one of the new houses and in support of the coal-fired power plant.
- A resident in the area who has lived there for 20+ years and is very angry about both the new housing development project and the idea to build a new power plant (there is already a lot of industry nearby)
- A marine biologist who works at Hubbs-SeaWorld Marine Fish Hatchery, located within the Agua Hedionda Lagoon
- The owner of the Carlsbad Aquafarm, which is located within the Agua Hedionda Lagoon
- The CEO of the coal power plant company
- The City Council members

Students should research the science connected to these issues, (perhaps with a StoryMap) but then also consider their role and how they want to argue in light of their role. They will present an argument for or against the low-cost housing development to the City Council. Specifically, students should think about how the chemistry of the lagoon might be affected by a large CO₂ emitter. City Council members should research how the actual Carlsbad City Council might vote on this. After hearing from the stakeholders, the City Council votes on the proposal.

Once the City Council has voted, each student writes a report on what they learned during this process and how they would cast their own vote, if this scenario presented itself. They should include in their report the concerns raised by each of the stakeholders, but ultimately, make their own judgment on the proposal, and even offer an alternative to the coal-fired power plant.
### Learning and Instructional Sequence (an example)

<table>
<thead>
<tr>
<th>SE Stage</th>
<th>Activity/Lesson/Idea (Lesson 1: Keeling’s Curve – The CO2 Story + Ocean Acidification)</th>
<th>Science/Engineering Practice or Crosscutting Concept Foregrounded</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engage</strong></td>
<td>• Show the class the video by the American Museum of Natural History called “Science Bulletins: Keeling’s Curve - The Story of CO₂” (<a href="https://www.youtube.com/watch?v=0Z8g-smE2sk">https://www.youtube.com/watch?v=0Z8g-smE2sk</a>)</td>
<td><strong>Crosscutting Concepts</strong></td>
</tr>
<tr>
<td><strong>Explore</strong></td>
<td>• Next, students turn to a partner and share what they processed</td>
<td><strong>Stability and Change</strong></td>
</tr>
<tr>
<td></td>
<td>• Pass out the questions for “Keeling’s Curve – The Story of CO₂”. Each group divides up the worksheet so each student is tasked with finding out the answer to one question.</td>
<td>• Much of science deals with constructing explanations of how things change and how they remain stable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Feedback (negative or positive) can stabilize or destabilize a system.</td>
</tr>
<tr>
<td></td>
<td><strong>Explain</strong></td>
<td><strong>Cause and Effect</strong></td>
</tr>
<tr>
<td></td>
<td>• Display the graph of the Keeling Curve on the board. Explain that the graph displayed shows the Keeling curve with CO₂ levels measured in parts per million (or ppm) on the y-axis on the left and years on the x-axis. The purple line shows levels of carbon dioxide in the air; the dark blue plots carbon dioxide levels in seawater; and the light blue plots seawater pH</td>
<td>• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.</td>
</tr>
<tr>
<td><strong>Elaborate/Extend</strong></td>
<td>• (Through the experiment that shows seawater uptake of CO₂ gas and a change in pH as a result)</td>
<td></td>
</tr>
<tr>
<td><strong>Evaluate</strong></td>
<td>• Closure Activity: Hand out two strips of paper per students. On one strip, instruct them to answer this question, “What effect does an increase in atmospheric carbon dioxide have on ocean chemistry?” On the other, write one question you would like to ask a climate scientist</td>
<td></td>
</tr>
</tbody>
</table>
## Lesson Plan #1:
### Keeling’s Curve – The Story of CO₂

**Grade Level:** High School  
**Periods:** 1 (60 minutes)  
**Content:** Climate Science, Marine Chemistry, Ocean Acidification

Preparation Time: 60 minutes  
Class Time: 60 minutes  
**Total Time:** 120 minutes

### Materials:
- Computer with internet access (best if you can project your screen for the whole class to see)
- Worksheet “Keeling’s Curve – The Story of CO₂” (included)
- 2 medium-sized clear glass bowls per group
- Universal indicator dye (McCrum, Bromothymol blue, or cabbage juice pH indicator – recipe at the end of the lesson)
- Small plastic cups (8-12 oz); 1 for each group of students
- Paper straws; 1 for each group of students
- Safety goggles; 1 for each student
- 4 tea light candles per group (or other floating candles)
- Matches or a lighter
- White paper (one per group)
- Strips of paper (2 per student) to write exit slip questions on

### Objectives

<table>
<thead>
<tr>
<th>Performance Expectation(s) per NGSS</th>
<th>Content Objective(s)</th>
<th>Language Objective</th>
</tr>
</thead>
</table>
| **HS-ESS3-5.** Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts on Earth systems. | By the end of class, students will be able to (SWBAT)  
  - Explain how the rise in atmospheric carbon dioxide changes the pH of seawater, making it more acidic  
  As evidenced by:  
  - Exit slip | By the end of class, SWBAT  
  - Writing a coherent and thorough explanation of the interrelationship between seawater pH and atmospheric carbon dioxide (abiotic factors) |
### Academic Language Considerations

<table>
<thead>
<tr>
<th>Vocabulary &amp; Concepts</th>
<th>Language of Instruction</th>
<th>Language of Production</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Both new vocabulary and review vocabulary that is pertinent to this lesson (review vocab is italicized)</em></td>
<td><em>How language will be used throughout the lesson that students will need to comprehend</em></td>
<td><em>How students will need to use language to demonstrate proficiency with the language objective.</em></td>
</tr>
<tr>
<td>• climate change</td>
<td>• What is climate change?</td>
<td>• Able to explain that carbon dioxide is a naturally occurring gas on Earth and that we need it and the greenhouse gas effect to keep the planet warm; however we are currently releasing too much carbon dioxide and that is warming the planet too much.</td>
</tr>
<tr>
<td>• greenhouse gases <em>(and GHG effect)</em></td>
<td>• Why is climate change controversial?</td>
<td>• Able to explain that carbon dioxide is the largest contributor to climate change</td>
</tr>
<tr>
<td>• Keeling Curve</td>
<td>• What gas is the largest contributor to climate change?</td>
<td>• Able to explain that the Keeling Curve is a measure of carbon dioxide in the atmosphere and shows that carbon dioxide levels have been increasing since 1958.</td>
</tr>
<tr>
<td>• pH, <em>acidic, basic</em></td>
<td>• What are the main sources of carbon dioxide emissions?</td>
<td>• Able to explain that rising CO₂ levels in the atmosphere lead to more acidic oceans.</td>
</tr>
<tr>
<td>• ocean acidification</td>
<td>• What is the Keeling Curve?</td>
<td>• Able to explain that carbonic acid is formed when carbon dioxide dissolves in seawater.</td>
</tr>
<tr>
<td>• anthropogenic</td>
<td>• How do rising atmospheric carbon dioxide levels affect ocean chemistry (pH)?</td>
<td></td>
</tr>
<tr>
<td>• oxygen</td>
<td>• What acid is formed when carbon dioxide dissolves into seawater?</td>
<td></td>
</tr>
<tr>
<td>• carbon dioxide</td>
<td>• What effect does this acid have on seawater?</td>
<td></td>
</tr>
<tr>
<td>• carbonic acid</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Preparation

<table>
<thead>
<tr>
<th>Preparation</th>
<th>1. Load “Keeling’s Curve – The Story of CO₂” video on your computer (or access it via the web)</th>
</tr>
</thead>
<tbody>
<tr>
<td>~60 minutes (depending on if you are using cabbage juice pH indicator dye)</td>
<td>2. Obtain materials needed for Air-Sea Gas Exchange activity.</td>
</tr>
<tr>
<td></td>
<td>3. If using cabbage juice as a pH indicator dye, prepare this in advance</td>
</tr>
<tr>
<td></td>
<td>4. Print out worksheet “Keeling’s Curve – The Story of CO₂”</td>
</tr>
<tr>
<td></td>
<td>5. Cut up paper strips to hand out as exit slip questions.</td>
</tr>
</tbody>
</table>
## Overview of Lesson

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Teacher Actions</th>
<th>Student Actions</th>
<th>Monitoring Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-10 minutes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Warm-Up: Think-Pair-Share** | - Display the prompt on the board. “What are the causes of climate change? How can we measure changes to the Earth’s climate? Have you ever heard of the Keeling Curve? If so, what is it?” Instruct students to think of their answers, then pair up with a neighbor and share their thoughts.  
- Lead a discussion with the entire class, inviting partner groups to share what they discussed. If students are unclear about what climate change is, review with them greenhouse gases and the greenhouse gas effect; use the PowerPoint slides included in the Dropbox link provided with this unit to give your students some background context. | - (I) Thinking of their response to themselves  
- (P) Sharing with their neighbor  
- (W) Sharing their thoughts with the class | - What is climate change?  
- What causes climate change?  
- How is climate change measured?  
- What is the Keeling curve?  
- What have you heard about climate change on TV, in the newspaper, or on the radio? |

| 20 min | **Activity: Keeling Curve – The Story of CO₂** | - Show the class the video by the American Museum of Natural History called “Science Bulletins: Keeling’s Curve - The Story of CO₂” ([https://www.youtube.com/watch?v=0Z8g-smE2sk](https://www.youtube.com/watch?v=0Z8g-smE2sk)); let your students know you will watch the video twice – the first time they should listen and take in what they can.  
- Next, students turn to a partner and share what they processed | - (I) Watching the video and listening  
- (P) Sharing with a partner what they remember from the video  
- (S) Working in groups to answer the questions on the worksheet | - What gas in our atmosphere is causing global warming?  
- Is there a difference between seasonal changes and long-term trends?  
- What natural activities might account for seasonal changes?  
- Overall are atmospheric carbon dioxide levels increasing or decreasing? |
- Pass out the questions for “Keeling’s Curve – The Story of CO₂”. Each group divides up the worksheet so each student is tasked with finding out the answer to one question.
- Show the video for a second time, instructing students to listen for the answer to their question.
- After showing the video, students write down the answer to their question and share their answer with their groups; students discuss the answer to question #5 together to come up with an answer.
- Using Popsicle sticks (or other polling technique), lead a discussion with the entire class.

<table>
<thead>
<tr>
<th>30 minutes</th>
<th><strong>Activity: Ocean Acidification in a Bowl (adapted from BIOACID)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Teachers Note: Make sure to practice this ahead of time and know which color shows a pH change, based on which indicator dye you are using</em></td>
</tr>
<tr>
<td></td>
<td>Display the graph of the Keeling Curve on the board. Explain that the graph displayed shows the Keeling curve with CO₂ levels measured in parts per million (or ppm) on the y-axis on the left and years on the x-axis. The purple line shows levels of carbon dioxide in the air; the dark blue plots carbon dioxide levels in seawater; and the light blue plots seawater pH; Note that the data only graphs these levels until about 2008, but that the upward trend has continued, and today, atmospheric CO₂ has reached 407 ppm (as of 4/17/16; check this website for the most up-to-date level <a href="https://scripps.ucsd.edu/programs/keelingcurve/">https://scripps.ucsd.edu/programs/keelingcurve/</a>)</td>
</tr>
<tr>
<td></td>
<td>Gases in the atmosphere exchange with gases in the ocean, influencing</td>
</tr>
<tr>
<td></td>
<td>(W) Sharing with the whole class what they learned</td>
</tr>
<tr>
<td></td>
<td>(S) Conducting the experiment</td>
</tr>
<tr>
<td></td>
<td>(I) Observing the changes in color in the water</td>
</tr>
<tr>
<td></td>
<td>(I) Writing notes and results of experiment in lab book</td>
</tr>
<tr>
<td></td>
<td>What does the Keeling curve tell us about carbon dioxide in the ocean? In which direction does it trend? (carbon dioxide has been increasing since measurements began in 1958)</td>
</tr>
<tr>
<td></td>
<td>How does that influence carbon dioxide in seawater? (Seawater takes up atmospheric carbon dioxide, so it seawater CO₂ or pCO₂ increases as well)</td>
</tr>
<tr>
<td></td>
<td>What does the graph tell us about carbon dioxide and pH in seawater (do they trend in the same direction or apart)? (pH decreases, or becomes more acidic, as pCO₂ increases)</td>
</tr>
</tbody>
</table>
ocean chemistry. Ask, “In which direction does seawater pH trend (is it increasing or decreasing)? When seawater pH decreases, does it become more basic or more acidic?” (Review pH with students, if needed. See the end of this lesson for a review activity.) In sum, the ocean absorbs CO$_2$, and this decreases pH (makes it more acidic). We can see this exchange in the following experiment.

- Set up your materials. Each group of students should have 2 medium-sized glass bowls filled with distilled water and pH indicator dye, one white piece of paper, and 4 candles. Note: the water in the bowls should be room temperature. Each group should also have a cup and a straw.
- Put on safety goggles.
- Instruct students to dip the cup into the bowl and fill up their cup with a small amount of water.
- Using the straw, students blow (do NOT suck!) air bubbles into the water in the cup. Note the color change. Alternatively, the teacher could demonstrate this in front of the class.
- What’s happening? The air in our exhalations is pumping carbon dioxide directly into the water, changing pH, as indicated in the color change of the water. When carbon dioxide reacts with seawater, carbonic acid is formed.
- What about when carbon dioxide isn’t pumped into water, but is simply present in the air surrounding the water? Let’s see...
- Explain that the water in the bowl represents the ocean. The candles represent the countries that emit the most carbon dioxide (China, United States, Russia, India; 2011

- When you blow into the water in the cup, what do you observe? (the color changes, indicating the water has become more acidic)
- What causes this change in color? (carbon dioxide from your breath)
- Do you expect we will see a change in the water’s pH when carbon dioxide is simply present in the air near water?
- Which 4 countries emit the most carbon dioxide overall (not per capita)? (China, U.S., Russia, India)
- What gas does fire need to burn? (oxygen)
- What gas does fire emit? (carbon dioxide)
- What do you observe when we introduce an atmosphere to our ocean system? (The fire eventually burns out?)
- Why? (Because it is using up all the oxygen)
- What do you observe about the color of the surface water? (It changes color too)
- Why? (It shows a change in pH from basic to more acidic as the “ocean” takes up the carbon dioxide emitted.)
Instruct students to place the candles in the water, wick side facing up.

- Teacher lights all the candles. Ask your students, “What gas does fire need to burn? (oxygen) What gas does fire emit? (carbon dioxide)”
- Instruct your students to place the second glass bowl over the first, rim to rim. This represents our atmosphere. What do they observe? (The fire eventually burns out? Why? Because it is using up all the oxygen. What do they observe about the color of the surface water? It changes color too. Why? It shows a change in pH from basic to more acidic as the “ocean” takes up the carbon dioxide emitted.)

5 minutes  **Closure: Question Strips**
- Hand out two strips of paper per students. On one strip, instruct them to answer this question, “What effect does an increase in atmospheric carbon dioxide have on ocean chemistry?” On the other strip, Instruct them to write down one question they would like to ask a climate scientist about climate change, its causes, and/or its impacts. The question can draw from something learned or presented today, or can draw from other things they’ve heard about climate change outside the classroom.
- Students have 5 minutes to complete and turn in their questions to the instructor as they leave the classroom.
- Display the questions students would ask a climate scientist on a “wonder board” in the classroom and pull questions at random another day to discuss as a class. OR

• (I) Thinking of the answer to the question posed and writing down their answer
• (I) Thinking of a question they would like to ask a climate scientist and writing down their question.
| invite a climate scientist to come present in your classroom and answer some of those questions. |   |
Think-Pair-Share

Today’s Questions:

What are the causes and impacts of climate change?
How can we measure changes to the Earth’s climate?
Have you ever heard of the Keeling Curve? If so, what is it?

You’ll have a minute to consider these questions silently. Then take two minutes to discuss your ideas with your neighbor.
Charles David Keeling was a climate scientist at Scripps Institution of Oceanography at UCSD in La Jolla, CA. Based on the video you just watched, answer the following questions:

1. An increase of what gas in our atmosphere is causing the globe to warm?

2. In which year did Keeling begin taking measurements of carbon dioxide (CO$_2$) from the Mauna Lao Observatory in Hawaii?

3. What seasonal trends did Keeling observe (when did CO$_2$ peak, when did CO$_2$ fall)? What accounts for this seasonal change?

4. Over the years, have atmospheric CO$_2$ levels increased or decreased overall? What level of carbon dioxide will we reach by the year 2100 if we continue to emit carbon dioxide at current levels (answer should be in ppm)?

5. The video argues that, “by reducing our use of fossil fuels, we can change the direction of the Keeling Curve.” Describe 3 ways we can reduce our use of fossil fuels.
Rising Carbon Dioxide (Keeling Curve) and Decreasing pH

R.A. Feely, NOAA (2008)
Supplementary Materials:

Recipe: Cabbage Juice pH Indicator

Materials:
- One red cabbage
- One large pot
- Water

Directions:
1. Chop red cabbage roughly and separate the pieces.
2. Place cabbage in a large pot and cover with water.
3. Heat the pot on your stove and cover with a lid. Make sure it does not boil over.
4. Heat for 30 minutes to 1 hour or until liquid is dark purple.
5. Strain cabbage pieces from the liquid, and allow the liquid to cool.
6. Store liquid in refrigerator until you are ready to use.
Supplementary Materials:

pH Worksheet

SAFETY GUIDELINES: We are working with some dangerous chemicals (the bleach and ammonia), so wear your safety goggles and only use the pipettes to make contact with the solutions. Do not get it on your skin!

Instructions: In front of you are 8 solutions, some basic and some acidic. Before testing your solutions, guess whether you think each one is acidic, neutral, or basic/alkaline. Record your guesses on your worksheet. Can you order them from acidic to alkaline, based on your guesses? Next, use your pipette to place a single drop of each solution onto a strip of blue pH paper. Based on the color that shows up and the pH scale below, can you guess where each solution falls along the scale?

<table>
<thead>
<tr>
<th>Solution</th>
<th>My Guess</th>
<th>Color on pH strip</th>
<th>Measured pH Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>My spit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seawater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bleach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lemon Juice</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coke/Pepsi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black Coffee</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soapy Water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pure Water</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SAFETY GUIDELINES: We are working with some dangerous chemicals (the bleach and ammonia), so wear your safety goggles and only use the pipettes to make contact with the solutions. Do not get it on your skin!

Instructions: In front of you are 8 solutions, some basic and some acidic. Before testing your solutions, guess whether you think each one is acidic, neutral, or basic/alkaline. Record your guesses on your worksheet. Can you order them from acidic to alkaline, based on your guesses?

Next, use your pipette to place a single drop of each solution onto a strip of blue pH paper. Based on the color that shows up and the pH scale below, can you guess where each solution falls along the scale?

<table>
<thead>
<tr>
<th>Solution</th>
<th>My Guess</th>
<th>Color on pH strip</th>
<th>Measured pH Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>My spit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td></td>
<td>LIGHT BLUE</td>
<td>10</td>
</tr>
<tr>
<td>Seawater</td>
<td></td>
<td>GREEN/BLUE</td>
<td>8</td>
</tr>
<tr>
<td>Bleach</td>
<td></td>
<td>DARK BLUE/PURPLE</td>
<td>13</td>
</tr>
<tr>
<td>Lemon Juice</td>
<td></td>
<td>YELLOW</td>
<td>2</td>
</tr>
<tr>
<td>Coke/Pepsi</td>
<td></td>
<td>YELLOW</td>
<td>2-3</td>
</tr>
<tr>
<td>Black Coffee</td>
<td></td>
<td>LIME GREEN</td>
<td>5</td>
</tr>
<tr>
<td>Soapy Water</td>
<td></td>
<td>BLUE/PURPLE</td>
<td>11-12</td>
</tr>
<tr>
<td>Pure Water</td>
<td></td>
<td>GREEN</td>
<td>7</td>
</tr>
</tbody>
</table>
Lesson Plan #2: Ocean Acidification

**Grade Level:** High School

**Periods:** 1 (60 minutes)

**Content:** Marine Science, Ocean Acidification

**Preparation Time:** 20 minutes

**Class Time:** 60 minutes

**Total Time:** 80 minutes

**Materials:**
- Strips of paper for raffle poem
- Print-outs of reading activity included in this unit (*What is Ocean Acidification* from Woods Hole Oceanographic Institution)
- Computer with internet access
- Projector

**Objectives**

<table>
<thead>
<tr>
<th>Performance Expectation(s) per NGSS</th>
<th>Content Objective(s)</th>
<th>Language Objective</th>
</tr>
</thead>
</table>
| HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. | By the end of class, students will be able to (SWBAT)
- Explain the causes and effects of ocean acidification and its impact on marine ecosystems
As evidenced by:
- A group concept map | By the end of class, SWBAT
- Draw and explain how various terms and concepts related to ocean acidification are connected. |

**Academic Language Considerations**

<table>
<thead>
<tr>
<th>Vocabulary &amp; Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Both new vocabulary and review vocabulary that is pertinent to this lesson (review vocab is italicized)</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Language of Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>How language will be used throughout the lesson that students will need to comprehend</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Language of Production</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>How students will need to use language to demonstrate proficiency with the language objective.</em></td>
</tr>
</tbody>
</table>

- **pH**
- **Keeling Curve**
- **Ocean acidification**
- **Marine calcifiers**
- **Pteropods**
- **Plankton**
- **Phytoplankton**
- **Diatoms**
- **Dinoflagellates**

- A number of new terms are identified in the reading activity titled “What is Ocean Acidification”. Students are instructed to box new terms and underline definitions
- Examples of language students will learn during instruction:
  - How much atmospheric carbon dioxide does the ocean absorb?
- Students summarize and explain the reading from their section to other group members, using new vocabulary learned
- Students construct a concept map as a group, using new terms and phrases learned
- Students create linguistic connections between new vocabulary terms and phrases
| Cyanobacteria | Zooplankton | Larvae | Industrial Revolution | Fossil fuels | Carbon dioxide | Anthropogenic | Thermocline | Global warming | Sea level rise | Proxy | Bicarbonate | Carbonate | Calcium carbonate | Paleocene-Eocene boundary |
|---------------|-------------|--------|-----------------------|-------------|---------------|---------------|-------------|--------------|----------------|----------------|------|-------------|-----------|----------------------|--------------------------|

- What compound is formed when seawater absorbs carbon dioxide?
- (See other questions under Monitoring Learning column below)

### Preparation

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Task</th>
</tr>
</thead>
</table>
| 20 minutes    | 1. Print out the reading activity included in this lesson (What is Ocean Acidification from Woods Hole Oceanographic Institution)  
2. Load the Scripps Plankton Camera website ([http://spc.ucsd.edu/](http://spc.ucsd.edu/)) onto your computer. Pre-identify phytoplankton (diatoms, dinoflagellates), zooplankton (copepods), pteropods (snail-like calcifying plankton), larvae, and eggs. |

### Overview of Lesson

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Teacher Actions</th>
<th>Student Actions (W, I, P, S)</th>
<th>Monitoring Learning</th>
</tr>
</thead>
</table>
| 5 minutes     | **Warm-Up: Raffle Poem**  
- Using strips of paper, instruct students to write a couple of phrases of something they learned yesterday (i.e. keeling curve, ocean pH decreasing)  
- Collect strips, mix them up and randomly display them on the board or lay on the floor.  
- Read them in the order they’re displayed (it will read like a poem)  
- With these cues, students will be reminded of the lessons from the previous class. Use those cues to | (I) Students write words, phrases, or sentences about what they learned in the last class about pH and ocean acidification on colored strips of paper | Probing questions from last class’ lessons, like  
- How does an increase in atmospheric carbon dioxide change surface water pH? |
|               |                 |                             |                     |
generate a discussion with some of your own review questions.  
- For example, you could ask, “How does carbon dioxide in the atmosphere change ocean surface water pH?”

| 30 min | **Activity: Ocean Acidification**  
- Tell students their assignment is to investigate some of the aspects of carbon dioxide in seawater, and impacts of reduced pH. Provide each student group (3 students) with a copy of the reading included at the end of this lesson (from Woods Hole Oceanographic Institution).  
- Students read through the article once, then work in groups to answer the questions on the inquiry worksheet. Each student is responsible for answering the questions at the end of his/her section. Then, each member of the group (starting with the person who had section 1, then 2, etc.) reports out what they learned in their section. As a group, students answer the analysis questions at the very end of the reading.  
- After reviewing the questions and answers together, as a group students develop a concept map forming connections between the new terms and phrases they just learned. |  
|  | - (W) Reading the raffle poem aloud; recalling lessons learned from the past class  
- (W) Discussing with the class key concepts related to the ocean acidification experiment conducted last class  
- (I) Reading the article on ocean acidification from Woods Hole Oceanographic Institution and answering questions related to their section  
- (S) Discussing with their groups the discussion questions included in the activity; creating a concept map  
- (W) discussing the article and ocean acidification  
- What atmospheric gas causes ocean acidification?  
- How much atmospheric carbon dioxide does the ocean absorb?  
- Are global warming and ocean acidification the same thing? How are they different and how are they similar?  
- How do scientist know what oceanic and atmospheric chemistry was like 800,000 years ago?  
- How is present day similar to the changes in Earth’s atmosphere and ocean 55 million years ago during the Paleocene-Eocene boundary? How is it different?  
- What is the average pH of seawater? What compound is formed when seawater absorbs carbon dioxide? |
<table>
<thead>
<tr>
<th><strong>Activity: Plankton</strong></th>
<th><strong>Brainstorming a list of organisms that will be affected by ocean acidification</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- The article mentioned several organisms that will be affected by ocean acidification. Brainstorm with your students to come up with a list of these organisms, known as marine calcifiers. Display these on the board.</td>
<td></td>
</tr>
<tr>
<td>- The article mentioned pteropods, a planktonic snail. Review with your students what plankton are (an umbrella term for tiny free floating organisms in the ocean; includes tiny organisms like phytoplankton and zooplankton, but also eggs and species in a larval stage).</td>
<td></td>
</tr>
<tr>
<td>- Open up your browser to the Scripps Plankton Camera at <a href="http://spc.ucsd.edu/">http://spc.ucsd.edu/</a>. Explain that scientists at Scripps have installed a camera at the end of the pier that takes pictures of the organisms floating by, even organisms at a microscopic level. Show them some of the images. Point out the phytoplankton (diatoms, dinoflagellates, cyanobacteria). These microscopic phytoplankton actually provide one of every two breaths we take. Point out larvae, eggs, zooplankton like copepods. Try to find and identify a pteropod.</td>
<td></td>
</tr>
<tr>
<td>- Ask, “Why do we care if plankton is adversely affected by ocean acidification?” (We care because plankton is the base of the food web and also provides us with oxygen...)</td>
<td></td>
</tr>
</tbody>
</table>

| **Which organisms are most at risk from ocean acidification?** |
| **In your own words, what are the two threats facing marine calcifiers?** |

<table>
<thead>
<tr>
<th><strong>10-15 minutes</strong></th>
<th><strong>Activity: Plankton</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Which organisms did the article mention are at risk of ocean acidification (which are the marine calcifiers)?</td>
<td></td>
</tr>
<tr>
<td>- What are plankton?</td>
<td></td>
</tr>
<tr>
<td>- Why do we care if plankton are affected by ocean acidification?</td>
<td></td>
</tr>
<tr>
<td>- Knowing that plankton provide one of every two breaths we breathe, would we add any other species to our list of organisms affected by ocean acidification?</td>
<td></td>
</tr>
</tbody>
</table>
Return to your list of organisms that will be affected by ocean acidification. Now that we know (1) plankton is the base of the food web, and (2) phytoplankton provide one of every two breaths we breathe, would we add any other organisms to that list (like species higher up the food web, humans)?

5 minutes **Closure: 3-2-1 Exit Slip**
- Instruct students to complete a 3-2-1 Exit Slip exercise. Write down 3 facts you learned today, 2 things you thought were beautiful, fascinating, or inspiring, and 1 question you still have.

- (I) Writing their exit slips
What Is Ocean Acidification?
From Woods Hole Oceanographic Institution (http://www.whoi.edu/ocean-acidification/)

Name: ___________________________ Date: ________________

PRE-READING Questions (think-pair-share)

1. What do you already know about ocean acidification?

2. Skim through the text and section headers. What do you want to learn from this article?

READ and MARK the text:
- BOX new/unfamiliar vocabulary.
- Underline definitions.
- Highlight main ideas.
- Write your connections, thoughts, questions here

SECTION 1:
What is Ocean Acidification?
Since the beginning of the Industrial Revolution, when humans began burning coal in large quantities, the world’s ocean water has gradually become more acidic. Like global warming, this phenomenon, which is known as ocean acidification, is a direct consequence of increasing levels of carbon dioxide (CO₂) in Earth’s atmosphere.

Prior to industrialization, the concentration of carbon dioxide in the atmosphere was 280 parts per million (ppm). With increased use of fossil fuels, that number is now approaching 400 ppm and the growth rate is accelerating. Scientists calculate that the ocean is currently absorbing about one quarter of the CO₂ that humans are emitting. When CO₂ combines with seawater, chemical reactions occur that reduce the seawater pH, hence the term ocean acidification.

Currently, about half of the anthropogenic (human-caused) CO₂ in the ocean is found in the upper 400 meters (1,200 feet) of the water
column, while the other half has penetrated into the lower thermocline and deep ocean. Density- and wind-driven circulation help mix the surface and deep waters in some high latitude and coastal regions, but for much of the open ocean, deep pH changes are expected to lag surface pH changes by a few centuries.

Ocean acidification and global warming are different problems, but are closely linked because they share the same root cause—human emissions of CO₂. The atmospheric concentration of CO₂ is now higher than it has been for the last 800,000 years and possibly higher than any time in the last 20 million years. Humans have thus far benefited from the ocean’s capacity to hold enormous amounts of carbon, including a large portion of this excess CO₂. Had the ocean not absorbed such vast quantities of CO₂, the atmospheric concentration would be even higher, and the environmental consequences of global warming (sea level rise, shifting weather patterns, more extreme weather events, etc.) and their associated socioeconomic impacts would likely be even more pronounced. However, the oceans cannot continue to absorb CO₂ at the current rate without undergoing significant changes in chemistry, biology, and ecosystem structure.

**QUESTIONS – SECTION 1:**

1.1: What atmospheric gas causes ocean acidification?

1.2: How much atmospheric carbon dioxide does the ocean absorb?

1.3: Are global warming and ocean acidification the same thing? How are they different and how are they similar?
SECTION 2:
Measuring Ocean Acidification: Past and Present

Scientists know that the oceans are absorbing CO₂ and subsequently becoming more acidic from measurements made on seawater collected during research cruises, which provide wide spatial coverage over a short time period, and from automated ocean carbon measurements on stationary moorings, which provide long-term, high-resolution data from a single location. These records can be extended back through time using what are known as chemical proxies to provide an indirect measurement of seawater carbonate chemistry. A proxy is a measurement from a natural archive (ice cores, corals, tree rings, marine sediments, etc.) that is used to infer past environmental conditions. For example, by analyzing the chemical composition of tiny fossil shells found in deep ocean sediments, scientists have developed ocean pH records from ancient times when there were no pH meters. Furthermore, because the ocean surface water is in approximate chemical balance, or equilibrium, with the atmosphere above it, a record of historical ocean pH can be inferred from atmospheric CO₂ records derived from Greenland and Antarctic ice cores, which contain air bubbles from the ancient atmosphere. Such evidence indicates that current atmospheric CO₂ concentrations and ocean pH levels are at unprecedented for at least the last 800,000 years.

Going back deeper in Earth history to the Paleocene-Eocene boundary about 55 million years ago, scientists have found geochemical evidence of a massive release of CO₂ accompanied by substantial warming and dissolution of shallow carbonate sediments in the ocean. Although somewhat analogous to what we are observing today, this CO₂ release occurred over several thousand years, much more slowly than what we are witnessing today, thus providing time for the oceans partially to buffer the change. In the geologic record, during periods of rapid environmental change, species have acclimated, adapted or gone extinct. Corals have undergone large extinction events in the past (such the Permian extinction 250 million years ago), and new coral species evolved to take their place, but it took millions of years to recover previous levels of biodiversity.

QUESTIONS – SECTION 2:

Question 2.1: How do scientists know what oceanic and atmospheric chemistry was like 800,000 years ago?
Question 2.2: How is present day similar to the changes in Earth’s atmosphere and ocean 55 million years ago during the Paleocene-Eocene boundary? How is it different?

SECTION 3: How is Ocean Acidification Affecting Ocean Chemistry?
Seawater has a pH of 8.2 on average because it contains naturally occurring alkaline ions that come primarily from weathering of continental rocks. When seawater absorbs carbon dioxide from the atmosphere, carbonic acid is produced (see Box 1), reducing the water’s pH. Since the dawn of industrialization, average surface ocean pH has decreased to about 8.1.

Because the pH scale is logarithmic (a change of 1 pH unit represents a tenfold change in acidity), this change represents a 26 percent increase in acidity over roughly 250 years, a rate that is 100 times faster than anything the ocean and its inhabitants have experienced in tens of millions of years.

Why is it important?
Acidification can affect many marine organisms, but especially those that build their shells and skeletons from calcium carbonate, such as corals, oysters, clams, mussels, snails, and phytoplankton and zooplankton, the tiny plants and animals that form the base of the marine food web.

These “marine calcifiers” face two potential threats associated with ocean acidification: 1) Their shells and skeletons may dissolve more readily as ocean pH decreases and seawater becomes more corrosive; and 2) When CO₂ dissolves in seawater, the water chemistry changes such that fewer carbonate ions, the primary building blocks for shells and skeletons, are available for uptake by marine organisms. Marine organisms that build shells or skeletons usually do so through an internal chemical process that converts bicarbonate to carbonate in order to form calcium carbonate.

Exactly how ocean acidification slows calcification rates, or shell formation, is not yet fully understood, but several mechanisms are being studied. Most hypotheses focus on the additional energy an organism must expend to build and maintain its calcium carbonate shells and skeletons in an increasingly corrosive environment. In the face of this extra energy expenditure, exposure to additional...
environmental stressors (increasing ocean temperatures, decreasing oxygen availability, disease, loss of habitat, etc.) will likely compound the problem.

These effects are already being documented in many marine organisms, particularly in tropical and deep-sea corals, some of which exhibit slower calcification rates under more acidic conditions. The impact on corals is of great concern because they produce massive calcium carbonate structures called reefs that provide habitat for many marine animals, including commercially important fish and shellfish species that use the reefs as nursery grounds. Coral reefs are vital to humans as sources of food and medicine, protection from storms, and the focus of eco-tourism. In addition to corals, studies have shown that acidification impairs the ability of some calcifying plankton, tiny floating plants and animals at the base of the food web, to build and maintain their shells. Scientists have also observed increased larval mortality rates of several commercially important fish and shellfish.

**What can we expect in the future?**
Ocean acidification is occurring at a rate 30 to 100 times faster than at any time during the last several million years driven by the rapid growth rate atmospheric CO\(_2\) that is almost unprecedented over geologic history. According to the Intergovernmental Panel on Climate Change (IPCC), economic and population scenarios predict that atmospheric CO\(_2\) levels could reach 500 ppm by 2050 and 800 ppm or more by the end of the century. This will not only lead to significant temperature increases in the atmosphere and ocean, but will further acidify ocean water, reducing the pH an estimated 0.3 to 0.4 units by 2100, a 150 percent increase in acidity over preindustrial times. Assuming a “business-as-usual” IPCC CO\(_2\) emission scenario, predictive models of ocean biogeochemistry project that surface waters of the Arctic and Southern Oceans will become undersaturated with aragonite (a more soluble form of calcium carbonate) within a few decades, meaning that these waters will become highly corrosive to the shells and skeletons of aragonite-producing marine calcifiers like planktonic marine snails known as pteropods.

Although ocean acidification has only recently emerged as a scientific issue, it has quickly raised serious concerns about the short-term impacts on marine organisms and the long-term health of the ocean. Scientists estimate that over the next few thousand years, 90 percent of anthropogenic CO\(_2\) emissions will be absorbed by the ocean. This may potentially affect biological and geochemical processes such as photosynthesis and nutrient cycling that are vital to marine ecosystems on which human society and many natural
systems rely. At the same time, marine organisms will face the enormous challenge of adapting to ocean acidification, warming water, and declining subsurface-ocean oxygen concentrations.

**QUESTIONS – SECTION 3:**

*Question 3.1: What is the average pH of seawater? What compound is formed when seawater absorbs carbon dioxide?*

*Question 3.2: Which organisms are most at risk from ocean acidification?*

*Question 3.3: In your own words, what are the two threats facing marine calcifiers?*

**POST-READING: Article Analysis**

1. In your own words, write a short (3-5 sentence summary of this article).

2. Why should humans care about ocean acidification and impacts to marine organisms?
Concept Map

Instructions: Using the words in the word bank, on the back of this sheet draw arrows or lines showing which terms are connected and explain what mechanisms or processes connect them. One word can have multiple connections. Everyone in your group must agree what the connection is. Start with one word - ocean acidification - in the center and build connections from there.

For example:

Students learn from instruction taught by the teacher.
The teacher creates learning opportunities for students (and learns from them as well!)

<table>
<thead>
<tr>
<th>Word Bank</th>
<th>Marine Calcifiers (corals, pteropods, oysters)</th>
<th>800 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial Revolution</td>
<td>Carbonic Acid</td>
<td>280 ppm</td>
</tr>
<tr>
<td>Coal</td>
<td>Seawater pH</td>
<td>400 ppm</td>
</tr>
<tr>
<td>Fossil Fuels</td>
<td>Paleocene-Eocene boundary</td>
<td>proxy</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>Ocean Acidification</td>
<td></td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Lesson Plan 3:
OA Impacts on Oysters and Mantis Shrimp

Grade Level: High School

Content: Marine Biology and Chemistry, Ocean Acidification

Preparation Time: 60 minutes
Class Time: 80 minutes
Total Time: 140 minutes

Materials:
- Canary in the Coal Mine prompt
- Computer with internet access
- Projector
- Wide-mouthed glass mason jars with lids (enough for 1 per student)
- Seawater (enough to fill all the jars, plus some for reserve); available for free at Scripps Pier
- Oyster shells (one per student; plus 2 as control); washed and dried. You can get them from your local seafood market like Point Loma Seafood or Catalina Offshore
- Masking tape
- Sharpie pen
- Kitchen scale
- pH meter (available on Amazon)
- Bike pump and extra pump cartridges (available at REI or sporting good store)
- Mantis shrimp slides
- Mantis shrimp worksheet

Objectives

<table>
<thead>
<tr>
<th>Content Standard(s)</th>
<th>Content Objective(s)</th>
<th>Language Objective</th>
</tr>
</thead>
</table>
| HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. | By the end of class, students will be able to (SWBAT)  
- Describe the impact ocean acidification will have on oysters and mantis shrimp; and  
- Make a prediction about how a sea grass ecosystem might be altered in the face of ocean acidification  
As evidenced by:  
- Mantis shrimp worksheet  
- Closure activity, a Day’s Dialogue | By the end of class, SWBAT  
- Students will be able to describe how a common idiom is used in language today, the significance of this phrase, and where the phrase came from.  
- Students will be able to describe how oysters and mantis shrimp will fare in the face of ocean acidification. |
### Academic Language Considerations

<table>
<thead>
<tr>
<th>Vocabulary &amp; Concepts</th>
<th>Language of Instruction</th>
<th>Language of Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both new vocabulary and review vocabulary that is pertinent to this lesson (review vocab is italicized)</td>
<td>How language will be used throughout the lesson that students will need to comprehend</td>
<td>How students will need to use language to demonstrate proficiency with the language objective.</td>
</tr>
<tr>
<td>“canary in a coal mine”</td>
<td>Where does the expression “canary in a coal mine” come from?</td>
<td>Able to use the idiom “canary in a coal mine” to refer to current marine science issues</td>
</tr>
<tr>
<td>exoskeleton</td>
<td>What does it mean today?</td>
<td>Able to explain how carbonated (more acidic) water might impact an oyster shell</td>
</tr>
<tr>
<td>mollusk</td>
<td>What marine calcifiers might be considered the canary in the coal mine today?</td>
<td>Able to state a hypothesis about how mantis shrimp might respond to a more acidic ocean</td>
</tr>
<tr>
<td>crustacean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>annelid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>vertebrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>stomatopod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>raptorial appendage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cavitation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Preparation

<table>
<thead>
<tr>
<th>Time</th>
<th>Tasks</th>
</tr>
</thead>
</table>
| 60 min | 1. Purchase your materials and collect seawater from Scripps Pier.  
2. Load the NOAA/PBS Newshour video on your computer.  
3. Set up the lab stations with materials needed for the oyster experiment.  
4. Print out oyster worksheet.  
5. Review mantis shrimp slides. |
### Overview of Lesson

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Teacher Actions</th>
<th>Student Actions (W, I, P, S)</th>
<th>Monitoring Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 min</td>
<td><strong>Warm-Up:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Display the “Canary in a Coal Mine” prompt on the board. Have a student read the history and meaning of canary in a coal mine aloud.</td>
<td>• (I) Thinking of the phrase “canary in a coal mine” and what it means today; thinking of an organism that is considered a canary in the coal mine</td>
<td>• Where does the expression “canary in a coal mine” come from?</td>
</tr>
<tr>
<td></td>
<td>• Instruct students to Think-Pair-Share with their neighbor and brainstorm which species could be described as the canary in the coal mine (there is no real correct answer here. The idea is to get them thinking about the last class’ lesson and the marine calcifiers that will be affected by ocean acidification).</td>
<td>• (P) Sharing their thoughts with a neighbor</td>
<td>• What does it mean today?</td>
</tr>
<tr>
<td></td>
<td>• Lead a discussion with the entire class. Highlight that oysters are one such marine calcifier.</td>
<td>• (W) Discussing with the class</td>
<td>• What marine calcifiers might be considered the canary in the coal mine today?</td>
</tr>
</tbody>
</table>

### Activity – Oysters and Ocean Acidification (adapted from NOAA Marine Sanctuaries experiment [http://sanctuaries.noaa.gov/education](http://sanctuaries.noaa.gov/education))

- Briefly introduce oysters. In addition to acting as a filter in estuaries, wetlands, and lagoons, they are a food source for many people and the oyster farming industry provides lots of jobs for people across the U.S.
- Show the video from NOAA and PBS Newshour, “Acidifying Waters Corrode Northwest Shellfish” [http://www.pmel.noaa.gov/co2/story/Ocean+Acidification%27s+impact+on+oysters+and+other+shellfish](http://www.pmel.noaa.gov/co2/story/Ocean+Acidification%27s+impact+on+oysters+and+other+shellfish)
- Set up the lab. Each lab station should have a set of glass jars (4-6), enough seawater to fill them, one oyster shell per jar, masking tape

### 30 min

- (W) Watching the short video on oysters and OA
- (S) Conducting the OA experiment on oysters
- (I) Filling out their worksheet

### Why are oysters important in their ecosystem? (they filter seawater, cleaning it)

- Why are oysters important to humans? (they filter seawater, they are a massive industry providing jobs to thousands of people)

### How much does your oyster weigh at the beginning of the experiment?

- What will happen when we pump CO₂ into the seawater? (it will become more acidic)

- What do you think will happen to your oyster
The instructor should also prep a scale (dry kitchen scale works well), a pH meter, extra seawater in a large jug, and a bicycle pump with extra cartridges (to carbonate the seawater).

- Have students weigh each shell and record this mass on their worksheet.
- Students fill each jar with seawater, leaving a little room at the top (the oyster shell will need to fit too, so make sure there is a little space).
- Use the bike pump to pump carbon dioxide into your jar of seawater. Make sure you reserve two shells to put into a jar with the regular non-carbonated seawater as your control. Ask students why this is important.
- Drop one oyster shell into each jar and make sure there is no air at the top. Fill up with additional seawater, if needed.
- Using a calibrated pH meter, measure pH of the seawater and have students record the number on their worksheets. Try to get a range of pH levels from pH 5 to pH 7.5. You can also put in a few drops of bromothymol blue (or another pH indicator) to see a color change in more acidified water.
- You may want to have pairs of students work together.
- Have students label jars with their names and record the starting pH in their notebooks.
- Set aside. After one week, have students measure pH and remove shells and dry them overnight.
- After shells are dry, ask students to weigh shells and record the mass.
- Students complete the worksheet, calculating percent weight change and graphing the change relative to pH level.

shell once it sits in carbonated seawater for one week?
- What is the weight of your oyster shell after one week?
- Did your oyster lose any mass sitting in carbonate seawater for one week? Why or why not?
**30 min**  
**Activity: Mantis Shrimp**  
- Using the slides provided, provide your students with background information about the mantis shrimp  
- Distribute the worksheet and instruct students to complete questions 1-3.  
- After they’ve completed the first 3 questions, review what an exoskeleton is and what it’s made of. Review hypothesis testing and give students a moment to think-pair-share with their neighbor to develop a hypothesis about mantis shrimp and how their exoskeleton will be affected by ocean acidification.  
- Students write their hypothesis on the worksheet (#4 and #5).  
- Review with the class the studies conducted on mantis shrimp by researchers at Scripps (using slides provided).  
- Have students complete the last questions on the worksheet. Based on what you learned about mantis shrimp, would you accept or reject your original hypothesis? What new questions do you have now based on these findings? How do you think mantis shrimp will fare in the face of ocean acidification? What about their prey?

**5 min**  
**Closure – Day’s Dialogue**  
- Assign each student a role as either (1) a larval oyster, (2) an adult oyster, (3) an adult mantis shrimp  
- Students take turns writing down a silent dialogue. For example, the mantis shrimp writes, “How was your day?” and passes the sheet of paper to the larval oyster, who writes, “not so good.”  
- Did you know what a mantis shrimp was before today?  
- What kind of animal do you think it is? (To which group does it belong?) Mollusk (snails, octopuses), Crustacean (lobsters, crabs), Annelid (segmented worms), Vertebrate (fishes, turtles)  
- These animals do not have a backbone. What do they use as a skeleton? What is an exoskeleton?  
- How do you think their exoskeleton will change with ocean acidification?  
- How do you think their strike will be affected with ocean acidification?
| I tried so hard to build my shell today, but I couldn’t find the carbonate I needed, and now I feel exhausted!” Etc. |   |   |
In the late 19\textsuperscript{th} and early 20\textsuperscript{th} centuries, coal miners would take a canary in a cage down into the mines with them. Canaries are more sensitive than humans to toxic gases, especially carbon monoxide, a colorless, odorless gas. If the miners saw the canary acting odd or if it died, they would know to leave the mine immediately. Today, it is used as a common expression to mean, "something or someone who - due to sensitivity to his, her, or its surroundings - acts as an indicator and early warning of possible adverse conditions or danger." It is often used in reference to environmental changes.

Think-Pair-Share:

Based on what you’ve learned about ocean acidification, which species do you think could be described as a canary in the coal mine (there are many correct answers)?
**Oyster Activity**

<table>
<thead>
<tr>
<th>Oyster Name or Number</th>
<th>Start</th>
<th></th>
<th>End</th>
<th></th>
<th>% Weight Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass</td>
<td>pH</td>
<td>Mass</td>
<td>pH</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Instructions:**
1. Weigh your oyster and those of the rest of your group. Record the mass at the beginning of the experiment.
2. Fill your jar with seawater, leaving a little space at the top (you will be dropping your oyster shell in, so make sure there is a little room).
3. Use the carbonate pump to pump carbon dioxide into your jar of seawater.
4. Drop one oyster shell into each jar and make sure there is no air at the top. Fill up with additional seawater if needed.
5. Use the pH meter to read what your pH level is. Try to get your pH level to somewhere between 5 and 7.5 pH. Work with your group members to do the same with their jars and record the beginning pH levels (try to get a variety).
6. Cover your jar with its lid and make sure it is screwed on tight. Label your oyster jar using the masking tape and make sure the name you’ve given it matches the name or number on your chart above.
7. Set aside.

**AFTER ONE WEEK**
1. Take your oyster out of the jar and let it dry overnight. Warning: it will be VERY smelly!
2. Record the pH of your seawater on your chart above.
3. Once dry, weigh your oyster again and record the weight.

**RESULTS**
1. Calculate the percent weight change for each oyster in your group.
   Calculating percent weight change:
   \[
   \frac{\text{Ending weight} - \text{beginning weight}}{\text{beginning weight}} \times 100
   \]
   Example: \((6-7)/7 \times 100 = -14\%\) change from beginning weight.
2. Graph your data below with pH on the x-axis and percent weight change on the y-axis

3. Explain in words what the graph illustrates.

4. In this activity, we introduced carbon dioxide to make the seawater more acidic. Can you think of a way to alter the seawater pH that would balance it (bring it back to basic)? (Teacher Note: this question is meant to get your students to achieve this performance expectation HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.)
Mantis Shrimp Worksheet

Instructions: In groups of 2, use the knowledge you learn about the mantis shrimp to complete the worksheet below.

1. Did you know what this animal was before today?

2. What kind of animal do you think it is? (To which group does it belong?)
   a. Mollusk (snails, octopuses)
   b. Crustacean (lobsters, crabs)
   c. Annelid (segmented worms)
   d. Vertebrate (fishes, turtles)

3. These animals do not have a backbone. What do they use as a skeleton?

4. Given what you’ve learned about ocean acidification so far, write a hypothesis about how you think their skeletons may or may not change due to ocean acidification.

5. Like you saw in the video, these animals smash hard-shelled prey. The ability to smash is very dependent on their skeleton. Given your hypothesis about how their skeletons may change with ocean acidification, how do you predict their strike might also change due to ocean acidification?

-------- STOP --------
WAIT FOR INSTRUCTION FROM YOUR TEACHER
6. Based on what you learned about mantis shrimp, would you accept or reject your original hypothesis?

7. What new questions do you have now based on the research findings presented to you?

8. Given what you know about how sea grass can influence carbon chemistry here in San Diego, How do you think mantis shrimp will fare in the face of ocean acidification? What about their prey?
Lesson Plan 4: How We Collect Data: the WavepHOx & Calculating pH

Grade Level: High School  Periods: 1+ (~75 minutes)

Content: Marine Science, Engineering

Preparation Time: 20 minutes  
Class Time: 75 minutes  
Total Time: 95 minutes

Materials:
- Computer with internet
- Projector
- Link to video of WavepHOx research (provided by Shannon Waters at Ocean Acidification workshop)
- WavepHOx worksheet
- Calculating pH worksheet
- Smartphone (one per 3-4 group of students)

Objectives

Performance Expectation(s) per NGSS

Builds towards HS-ESS3-5 (Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems) by addressing DCI 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)

Content Objective(s)

By the end of class, students will be able to (SWBAT)
- Interpret marine chemistry data collected with the WavepHOx
- Calculate pH using a live data set of other chemical properties and the CO₂Calc

As evidenced by:
- Completion of the WavepHOx worksheet
- Completion of the Calculating pH worksheet

Language Objective

By the end of class, SWBAT
- Translate graphs and data sets into meaningful explanations of marine chemistry
Academic Language Considerations

<table>
<thead>
<tr>
<th>Vocabulary &amp; Concepts</th>
<th>Language of Instruction</th>
<th>Language of Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both new vocabulary and review vocabulary that is pertinent to this lesson (review vocab is italicized)</td>
<td>How language will be used throughout the lesson that students will need to comprehend</td>
<td>How students will need to use language to demonstrate proficiency with the language objective.</td>
</tr>
</tbody>
</table>

- **Ocean acidification**
- **Climate change**
- **pH**
- **WavepHOx**
- **Longitude**
- **Latitude**
- Dissolved inorganic carbon (DIC)
- Total alkalinity (TA)
- **Oxygen**
- **Nitrogen**
- **Phosphorus**
- **Carbon dioxide**
- **Salt ions**
- **Sodium**
- **Chloride**
- **Calcium**
- **Magnesium**
- **Potassium**
- **Sulfate**
- **Carbonate**
- **Bicarbonate**

- What does a scientist look like?
- What does a scientist wear?
- When you think of a scientist, what is the scientist doing?
- Where is the scientist?
- What tools is the scientist using?
- Identify location and key features of the Lagoon
- Orient students to the features of the WavepHOx maps
- What does the title of each map indicate (0600 is the time)?
- What information is presented on the x-axis (longitude) and the y-axis (latitude)?
- What does the color bar indicate for the top three graphs (a range of temperature), the middle three graphs (a range of oxygen), and the bottom three graphs (a range of pH)?
- What do the zig-zag of dots across the lagoon indicate? (the points at which the WavepHOx took measurements)
  - What chemical elements are present in seawater? For example, what chemicals make up the salt in seawater? What other chemicals are present?
  - What is the chemical reaction of photosynthesis? What do plants need to make sugars? (carbon dioxide) What is the byproduct of photosynthesis (oxygen)?
- Students will describe a scientist
- Students will interpret graphs and data sets
- Students will describe the role photosynthesis and respiration play in determining the pH of seawater
### Preparation

20 min

1. Print out the two worksheets included: *WavepHOx Worksheet* and *Calculating pH*
2. Load videos onto computer
4. Download the CO2Calc app onto your smartphone and test it out

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Teacher Actions</th>
<th>Student Actions</th>
<th>Monitoring Learning</th>
</tr>
</thead>
</table>
| 15 min        | **Warm-Up: Visualization**  
- Begin today’s class with a visualization:  
- Instruct the students to take a moment and think of a scientist. Without talking, think about what the scientist is wearing, what the scientist is doing, where the scientist is doing research, what tools the scientist is using (be careful not to use pronouns!). Then say...  
- Raise your hand if the scientist you imagined was a man.  
- Raise your hand if the scientist you imagined was old.  
- Raise your hand if the scientist you imagined had glasses.  
- Raise your hand if the scientist you imagined was in a lab.  
- Raise your hand if the scientist was alone in his lab.  
- Well scientists come in all shapes, sizes, and ages and use a variety of methods and instruments to study and observe ocean ecosystems. What we think of as “the scientist” – the old man in a lab by himself peering into a microscope – isn’t always true.  
- For the past week, we’ve been learning about climate change and ocean acidification – a topic of active research around the world. Let’s take | **(I) Thinking about and visualizing a scientist**  
**(W)** - Responding to teacher’s cues about what a scientist looks like, does, where he/she does research  
- **(W)** Watching the video of their teacher participating in research using the WavepHOx (and feeling inspired by cool science!) | **What does a scientist look like?**  
**What does a scientist wear?**  
**When you think of a scientist, what is the scientist doing?**  
**Where is the scientist?**  
**What tools is the scientist using?** |

<p>| <strong>What will the teacher present?</strong> | <strong>What is the teacher going to say?</strong> | <strong>What will the teacher be doing?</strong> | <strong>What do you expect the students will be doing?</strong> | <strong>What questions will you ask?</strong> | <strong>What content will you look or listen for?</strong> | <strong>How might you address misconceptions?</strong> |</p>
<table>
<thead>
<tr>
<th>Activity: Analyzing WavepHOx Data</th>
<th>Overview of Lesson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bring up Google Maps and zoom into the middle lagoon of the Agua Hedionda Lagoon (it should look like the maps displayed below without the color gradient).</td>
<td><strong>Activity</strong></td>
</tr>
<tr>
<td>Point out key features to orient students to the area. Highlight that this lagoon is North of LegoLand and situated between the 5 freeway and the ocean. Point out the Carlsbad Aquafarm, the Carlsbad Desalination Plant, the NRG Cabrillo Power plant, the train tracks, the recreation facilities. Underscore that this is a highly impacted lagoon. Display the WavepHOx data maps for the whole class to see and orient them to the information presented. For example, what does the title of each map indicate (0600 is the time)? What information is presented on the x-axis (longitude) and the y-axis (latitude)? What does the color bar indicate for the top three graphs (a range of temperature), the middle three graphs (a range of oxygen), and the bottom three graphs (a range of pH)? Explain that the zig-zag of dots across the lagoon show the points at which the WavepHOx took measurements. Students work in pairs to complete the worksheet, interpreting the data.</td>
<td><strong>Identify location and key features of the Lagoon</strong></td>
</tr>
</tbody>
</table>

a look at some scientists at Scripps Institution of Oceanography who are measuring ocean pH and oxygen right here in San Diego at the Agua Hedionda Lagoon. Show the video of teachers and researchers conducting research with the WavepHOx at the Agua Hedionda Lagoon (will be made accessible via the Dropbox link provided).
and making claims backed by evidence presented with the maps.
<table>
<thead>
<tr>
<th>Activity – Calculating pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The pH of the lagoon (or any water body) is a calculation based on a combination of chemical parameters. These include dissolved inorganic carbon (DIC), total alkalinity (TA), temperature, and salinity among others. We can calculate the pH even if we only know the measurements for some of these parameters. In this activity, students access a live dataset obtain measurements and then calculates pH based on those measurements.</td>
</tr>
<tr>
<td>• Begin with a brainstorm with your students about what chemical elements are in seawater (salt ions like sodium, chloride, calcium, magnesium, potassium, sulfate; carbon as carbon dioxide, carbonate, bicarbonate; oxygen, nitrogen in various forms, phosphorous); write these on the board as they are mentioned; explain that the various forms of carbon all together are known as dissolved inorganic carbon (DIC = [CO$_2$] + [HCO$_3$] + [CO$_3^{2-}$]); total alkalinity is represented by TA = [HCO$_3$] + 2[CO$_3^{2-}$] + [B(OH)$_4$] + [OH] – [H$^+$]; together, these elements all play a role in determining the pH of seawater</td>
</tr>
<tr>
<td>• We can calculate the pH even if we only know the measurements for some of these parameters.</td>
</tr>
<tr>
<td>• Hand out the worksheet “Calculating pH”</td>
</tr>
<tr>
<td>• Walk students through the instruction for downloading the CO$_2$Calc app to their phones; guide them through the first example</td>
</tr>
<tr>
<td>• Students work in small groups to complete the rest of the worksheet on their own</td>
</tr>
</tbody>
</table>

<p>| (W) Brainstorming what chemical elements are present in seawater; |
| (W) Listening to the teacher; learning how to download the CO$_2$Calc and how to navigate the IPACOA website |
| What chemical elements are present in seawater? For example, what chemicals make up the salt in seawater? What other chemicals are present? |
| What is the chemical reaction of photosynthesis? What do plants need to make sugars? (carbon dioxide) What is the byproduct of photosynthesis (oxygen)? |</p>
<table>
<thead>
<tr>
<th>10 min</th>
<th><strong>Closure</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• While climate change and ocean acidification are huge issues we’re facing, we’re also very intelligent beings that can create and engineer solutions to improve our future outlook.</td>
</tr>
<tr>
<td></td>
<td>• What are 2 things you can commit to doing in your daily life that you know can positively affect the ocean or reduce your carbon footprint. How will you hold yourself accountable? Will you make a chart? Will you tell someone about your personal challenge?</td>
</tr>
</tbody>
</table>
**WavepHOx Worksheet**

**Instructions:** Using the maps below, answer the following questions about the chemical properties measured in the Agua Hedionda Lagoon. What patterns do you see?

1. Estimate the average temperature in the lagoon (expressed as °C)...
   a. At 6AM
   b. At 8AM
   c. At 10AM

2. What is one claim you can make about temperature in the lagoon, based on the evidence above? (I.e. what trend do you observe in regard to temperature?)

3. Estimate the average percent saturation of oxygen in the lagoon...
   a. At 6AM
   b. At 8AM
   c. At 10AM
4. What is one claim you can make about oxygen in the lagoon, based on the evidence above? (I.e. what trend do you observe in regard to oxygen?)

5. Estimate the average pH of the lagoon...
   a. At 6AM
   b. At 8AM
   c. At 10AM

6. What is one claim you can make about pH in the lagoon, based on the evidence above? (I.e. what trend do you observe in regard to pH?)

7. Photosynthesis is a natural process that occurs during daylight that involves the exchange of oxygen and carbon dioxide gases in green plants. Write the chemical equation for photosynthesis below:

8. Is photosynthesis occurring in the lagoon? Is so, how do you know? If not, how do you know?

9. What relationship do you observe between oxygen and pH levels in the lagoon (do they trend in the same direction or in opposite directions)?

10. After the sun sets, how would you hypothesize the oxygen concentration in the lagoon to change?

11. After the sun sets, how would you hypothesize the pH level in the lagoon to change?
Calculating pH

The pH of the lagoon (or any water body) is a calculation based on a combination of chemical parameters. These include dissolved inorganic carbon (DIC), total alkalinity (TA), temperature, and salinity among others. We can calculate the pH even if we only know the measurements of some of these parameters. Scripps Institution of Oceanography monitors a shore station called the Burkolator (named after marine chemist Burke Hale at Oregon State University). It’s a stationary sensor located in the Agua Hedionda Lagoon in Carlsbad near the Carlsbad Aquafarm. Among other things, it measures temperature, salinity, dissolved inorganic carbon, and total alkalinity. We can plug this data into our CO₂Calculator (developed by US Geological Survey) and calculate the pH of the lagoon on a given day at a given time.

Instructions:
- Download the CO₂Calc (developed by US Geological Survey) from the App Store (iPhone). If using an android, download the CO₂Calc developed by KKS Engineering on Google Play.
- Open your web browser to http://www.ipacoa.org/
- Click on the “Data Explorer” button.
- On the left, click on “Fixed Platforms”
- Scroll down until you see “SCCOOS Carlsbad Burkolator”. Click on it. Information for that shore station will appear.
- Notice that our graph on the lower half of the window shows a month or two of data. Scroll over the graph left to right and notice how the day, time, and data changes. Click on “salinity” in the box “SCCOOS Burkolator at Carlsbad Aquafarm” and notice how now the salinity data is displayed instead of total alkalinity.

Assignment: Find the pH value for the following days and times.

Example: March 29 @ 5AM
1. Make sure “alkalinity” within the “SCCOOS Burkolator at Carlsbad Aquafarm” box is selected.
2. Scroll over the graph until you find March 29, 2016 at 5:00AM. Write down the total alkalinity at that time (2185.2 µmol/kg).
3. Repeat with dissolved inorganic carbon (DIC or TCO₂) (2146.1 µmol/kg), salinity (29 psu), and temperature (58.2° F). Use an online calculator to convert Fahrenheit to Celsius (14.56° C).
4. Plug your numbers for total alkalinity, DIC, salinity and temperature into the CO₂Calc on your smartphone (make sure the “input” tab is selected at the bottom). Leave the other fields blank (note: TA is total alkalinity, TCO₂ is DIC). Click “calculate”. Record the pH level that’s displayed (7.632).
Your Turn (times can be approximate):

1. Select today’s date at 2AM.
   a. What is the total alkalinity (TA) level?
   
   b. What is the dissolved inorganic carbon (DIC) level?
   
   c. What is the temperature?
   
   d. What is the salinity?
   
   e. Calculate the pH.

2. Select yesterday’s date at 2PM.
   a. What is the total alkalinity (TA) level?
   
   b. What is the dissolved inorganic carbon (DIC) level?
   
   c. What is the temperature?
   
   d. What is the salinity?
   
   e. Calculate the pH.

3. Is pH higher or lower in the afternoon? Why do you think this is?
Performance Task

Performance Expectation Addressed:
HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Description of Performance Task

Upon completion of the lesson plans included in this unit, students will have a foundational understanding of climate change and ocean acidification and will be ready to evaluate ideas and proposals that would directly or indirectly influence the chemical properties of the Agua Hedionda Lagoon and the marine organisms that live there. To demonstrate their knowledge, students evaluate a (hypothetical) proposal to build a coal-fired power plant at the Agua Hedionda Lagoon.

Background: The price of buying a home in San Diego County is increasing, and the City Council Members in Carlsbad have been under pressure to approve low-cost housing near the Agua Hedionda Lagoon where the Strawberry Fields now sit (map). The housing development project was approved, and construction will begin within the next couple of months. These homes will need energy to power them though, and so - to keep costs low to homeowners – Coal-4-U power suppliers has proposed to build a coal-fired power plant nearby (coal is the cheapest fossil fuel, but also the biggest polluter of carbon dioxide; teachers note: you can either provide that information about coal or assign that research as part of the assignment). The City Council must vote on a decision to approve or deny the proposal from Coal-4-U after hearing from all the stakeholders.

Students are assigned roles based on the various stakeholders involved. Stakeholders include:
- A person interested in buying one of the new houses and in support of the coal-fired power plant.
- A resident in the area who has lived there for 20+ years and is very angry about both the new housing development project and the idea to build a new power plant (there is already a lot of industry nearby)
- A marine biologist who works at Hubbs-SeaWorld Marine Fish Hatchery, located within the Agua Hedionda Lagoon
- The owner of the Carlsbad Aquafarm, which is located within the Agua Hedionda Lagoon
- The CEO of the coal power plant company
- The City Council members

Students should research the science connected to these issues, (perhaps with a StoryMap) but then also consider their role and how they want to argue in light of their role. They will present an argument for or against the low-cost housing development to the City Council. Specifically, students should think about how the chemistry of the lagoon might be affected by a large CO2 emitter. City Council members should research how the actual Carlsbad City Council might vote on this. After hearing from the stakeholders, the City Council votes on the proposal.

Once the City Council has voted, each student writes a report on what they learned during this process and how they would cast their own vote, if this scenario presented itself. They should include in their report the concerns raised by each of the stakeholders, but ultimately, make their own judgment on the proposal, and even offer an alternative to the coal-fired power plant.
APPENDIX C.
WORKSHOP EVALUATION RESPONSES

Stand-Up for Science:
Lessons on Ocean Acidification from the Agua Hedionda Lagoon

Workshop Evaluation

Please place an X mark in the box that best represents your opinions on this workshop. Your honest opinion is appreciated.

1. As a result of participating in this workshop, I feel informed about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

2. As a result of participating in this workshop, I feel prepared to teach my students about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

3. The experiments and activities conducted in this workshop will help my students conceptualize the chemical changes that result from ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

4. It is important to me that my students have access to data sets that are the result of active and ongoing research.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
5. Teaching my students about the WavpHox and other novel ways to conduct research will get them excited about science.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

6. Overall, I would rate this workshop...

<table>
<thead>
<tr>
<th>Terrible</th>
<th>Bad</th>
<th>OK</th>
<th>Good</th>
<th>Awesome!</th>
</tr>
</thead>
</table>

7. My favorite part of the workshop was...

Because...

8. My least favorite part of the workshop was...

Because...

9. My favorite lesson plans are...

Because...

10. Any other comments?
Stand-Up for Science: Lessons on Ocean Acidification from the Agua Hedionda Lagoon

Workshop Evaluation

Please place an X mark in the box that best represents your opinions on this workshop. Your honest opinion is appreciated.

1. As a result of participating in this workshop, I feel informed about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. As a result of participating in this workshop, I feel prepared to teach my students about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. The experiments and activities conducted in this workshop will help my students conceptualize the chemical changes that result from ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. It is important to me that my students have access to data sets that are the result of active and on-going research.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. Teaching my students about the Wayptlox and other novel ways to conduct research will get them excited about science.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

6. Overall, I would rate this workshop...

<table>
<thead>
<tr>
<th>Terrible</th>
<th>Bad</th>
<th>OK</th>
<th>Good</th>
<th>Awesome!</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

7. My favorite part of the workshop was...

```
Cute Paddleboarding
```

Because...

```
Get to see some of areas in
designed this type of data
Is collected / novel way of collecting data implement.
```

8. My least favorite part of the workshop was...

```
N/A
```

Because...

```
I was engaged / interested the whole time!
```

9. My favorite lesson plans are...

```
- Really liked keeping core a lesson of Co2
- Hands on LABS
- Mantis Shrimp!
```

Because...

```
Great visualization for student materials are easy to implement / friendly.
```

10. Any other comments?

```
The blend of activities was well balanced and the performance task was a great way to send the lesson home in action last week.
```

Would've liked to see Wayptlox in action next time.

75
Stand-Up for Science:
Lessons on Ocean Acidification from the Agua Hedionda Lagoon

Workshop Evaluation

Please place an X mark in the box that best represents your opinions on this workshop. Your honest opinion is appreciated.

1. As a result of participating in this workshop, I feel informed about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. As a result of participating in this workshop, I feel prepared to teach my students about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. The experiments and activities conducted in this workshop will help my students conceptualize the chemical changes that result from ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. It is important to me that my students have access to data sets that are the result of active and on-going research.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. Teaching my students about the WavpHox and other novel ways to conduct research will get them excited about science.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>∧</td>
</tr>
</tbody>
</table>

6. Overall, I would rate this workshop...

<table>
<thead>
<tr>
<th>Terrible</th>
<th>Bad</th>
<th>OK</th>
<th>Good</th>
<th>Awesome!</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. My favorite part of the workshop was...

Because...

8. My least favorite part of the workshop was...

Because...

9. My favorite lesson plans are...

Because...

10. Any other comments?
Stand-Up for Science:  
Lessons on Ocean Acidification from the Agua Hedionda Lagoon

Workshop Evaluation

Please place an X mark in the box that best represents your opinions on this workshop. Your honest opinion is appreciated.

1. As a result of participating in this workshop, I feel informed about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. As a result of participating in this workshop, I feel prepared to teach my students about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. The experiments and activities conducted in this workshop will help my students conceptualize the chemical changes that result from ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. It is important to me that my students have access to data sets that are the result of active and on-going research.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

78
5. Teaching my students about the WavpHox and other novel ways to conduct research will get them excited about science.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

6. Overall, I would rate this workshop...

<table>
<thead>
<tr>
<th>Terrible</th>
<th>Bad</th>
<th>OK</th>
<th>Good</th>
<th>Awesome!</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

7. My favorite part of the workshop was... **LAB ACTIVITIES**

Because... **ADD TO MY CURRICULUM**

8. My least favorite part of the workshop was...

Because...

9. My favorite lesson plans are...

**OYSTER ACTIVITY**

Because... **SHOW STUDENTS WHAT RESEARCHERS ACTUALLY DO.**

10. Any other comments?

**GREAT JOB. GOOD LUCK IN THE FUTURE.**
Stand-Up for Science:
Lessons on Ocean Acidification from the Agua Hedionda Lagoon

Workshop Evaluation

Please place an X mark in the box that best represents your opinions on this workshop. Your honest opinion is appreciated.

1. As a result of participating in this workshop, I feel informed about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

2. As a result of participating in this workshop, I feel prepared to teach my students about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

3. The experiments and activities conducted in this workshop will help my students conceptualize the chemical changes that result from ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

4. It is important to me that my students have access to data sets that are the result of active and on-going research.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
5. Teaching my students about the WavpHox and other novel ways to conduct research will get them excited about science.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

6. Overall, I would rate this workshop...

<table>
<thead>
<tr>
<th>Terrible</th>
<th>Bad</th>
<th>OK</th>
<th>Good</th>
<th>Awesome!</th>
</tr>
</thead>
</table>

7. My favorite part of the workshop was...

the lesson plans

Because... seeing already developed curriculum makes it much much easier to bring current science research into my classroom.

8. My least favorite part of the workshop was...

the length & difficulty of the readings

Because...

the level is a little too high for my students.

maybe even me.

9. My favorite lesson plans are...

the ones where the students got to mess around w/ tangible items

Because...

they need the physical engagement & it does get them engaged.

10. Any other comments?

you did a great job creating the lesson plans. Very well thought out & very thoughtful.
Stand-Up for Science:  
Lessons on Ocean Acidification from the Agua Hedionda Lagoon

Workshop Evaluation

Please place an X mark in the box that best represents your opinions on this workshop. Your honest opinion is appreciated.

1. As a result of participating in this workshop, I feel informed about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

2. As a result of participating in this workshop, I feel prepared to teach my students about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

3. The experiments and activities conducted in this workshop will help my students conceptualize the chemical changes that result from ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

4. It is important to me that my students have access to data sets that are the result of active and on-going research.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
5. Teaching my students about the Wavpilox and other novel ways to conduct research will get them excited about science.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>X</strong></td>
</tr>
</tbody>
</table>

6. Overall, I would rate this workshop...

<table>
<thead>
<tr>
<th>Terrible</th>
<th>Bad</th>
<th>OK</th>
<th>Good</th>
<th>Awesome!</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>X</strong></td>
</tr>
</tbody>
</table>

7. My favorite part of the workshop was...

Playing with mantis shrimp

Because...

Mantis shrimp are AWESOME creatures! And animal examples really engage the bio lovers in a heavy lesson!

8. My least favorite part of the workshop was...

N/A

Because...

9. My favorite lesson plans are...

When the students engage in the science, like Lesson 4, analyzing the actual data.

Because....

10. Any other comments?

Maybe have participants present as if they were teaching to reinforce the knowledge and how to explain it to students.
Stand-Up for Science:
Lessons on Ocean Acidification from the Agua Hedionda Lagoon

Workshop Evaluation

Please place an X mark in the box that best represents your opinions on this workshop. Your honest opinion is appreciated.

1. As a result of participating in this workshop, I feel informed about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. As a result of participating in this workshop, I feel prepared to teach my students about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. The experiments and activities conducted in this workshop will help my students conceptualize the chemical changes that result from ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. It is important to me that my students have access to data sets that are the result of active and on-going research.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. Teaching my students about the WavpHlox and other novel ways to conduct research will get them excited about science.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

6. Overall, I would rate this workshop...

<table>
<thead>
<tr>
<th>Terrible</th>
<th>Bad</th>
<th>OK</th>
<th>Good</th>
<th>Awesome!</th>
</tr>
</thead>
</table>

7. My favorite part of the workshop was... Because...

8. My least favorite part of the workshop was...

Because...

9. My favorite lesson plans are... Because...

10. Any other comments?

Shannon — you prepared two amazing days of learning for science educators! The time spent at the aquarium — really added to it. You were absolutely terrific! Shannon!
Stand-Up for Science: Lessons on Ocean Acidification from the Agua Hedionda Lagoon

Workshop Evaluation

Please place an X mark in the box that best represents your opinions on this workshop. Your honest opinion is appreciated.

1. As a result of participating in this workshop, I feel informed about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td><img src="X" alt="X" /></td>
<td></td>
</tr>
</tbody>
</table>

2. As a result of participating in this workshop, I feel prepared to teach my students about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td><img src="X" alt="X" /></td>
<td></td>
</tr>
</tbody>
</table>

3. The experiments and activities conducted in this workshop will help my students conceptualize the chemical changes that result from ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td><img src="X" alt="X" /></td>
<td></td>
</tr>
</tbody>
</table>

4. It is important to me that my students have access to data sets that are the result of active and on-going research.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td><img src="X" alt="X" /></td>
<td></td>
</tr>
</tbody>
</table>
5. Teaching my students about the WavpHox and other novel ways to conduct research will get them excited about science.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(hopefully)</td>
</tr>
</tbody>
</table>

6. Overall, I would rate this workshop...

<table>
<thead>
<tr>
<th>Terrible</th>
<th>Bad</th>
<th>OK</th>
<th>Good</th>
<th>Awesome!</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. My favorite part of the workshop was...

   going out to the lagoon with the scuba gear

Because...

   if wasn't just sitting in a classroom learning about science, but being active researchers

8. My least favorite part of the workshop was...

Because...

9. My favorite lesson plans are...

   Lessons 2 & 3: Impacts on Biology by looking at oysters & munk's shrimp

Because...

   my students would be most interested in handling things or studying live animals

10. Any other comments?

    I can see a lot of time & effort was put into these lessons. Even though it is for HS and I teach MS, I can totally modify what you have provided.
Stand-Up for Science:
Lessons on Ocean Acidification from the Agua Hedionda Lagoon

Workshop Evaluation

Please place an X mark in the box that best represents your opinions on this workshop. Your honest opinion is appreciated.

1. As a result of participating in this workshop, I feel informed about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

2. As a result of participating in this workshop, I feel prepared to teach my students about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

3. The experiments and activities conducted in this workshop will help my students conceptualize the chemical changes that result from ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

4. It is important to me that my students have access to data sets that are the result of active and on-going research.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
5. Teaching my students about the WavpHox and other novel ways to conduct research will get them excited about science.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

6. Overall, I would rate this workshop...

<table>
<thead>
<tr>
<th>Terrible</th>
<th>Bad</th>
<th>OK</th>
<th>Good</th>
<th>Awesome!</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

7. My favorite part of the workshop was...

learning about what local scientists are doing & participating in their research

Because...

I think kids need to see what options are out there. They can learn about it by our experiences & sharing what we know or bringing in experts.

8. My least favorite part of the workshop was...

Nothing really. I just wish I could get my hands on some Mantis Shrimp!

Because...

9. My favorite lesson plans are...

Lesson 1: The Keeling curve b/c it's very universal. I can tie it into so many different lessons, not just ocean acidification. I also really like how the article was broken down into 4 parts, with guiding questions for each part, that will really help our EC & SPED kids.

Because...

10. Any other comments?

I love this! Please do more!
Workshop Evaluation

Please place an X mark in the box that best represents your opinions on this workshop. Your honest opinion is appreciated.

1. As a result of participating in this workshop, I feel informed about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

2. As a result of participating in this workshop, I feel prepared to teach my students about climate change and ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

3. The experiments and activities conducted in this workshop will help my students conceptualize the chemical changes that result from ocean acidification.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

4. It is important to me that my students have access to data sets that are the result of active and on-going research.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
5. Teaching my students about the WavpHox and other novel ways to conduct research will get them excited about science.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Overall, I would rate this workshop...

<table>
<thead>
<tr>
<th>Terrible</th>
<th>Bad</th>
<th>OK</th>
<th>Good</th>
<th>Awesome!</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. My favorite part of the workshop was...

getting new activities that incorporate real/current research.

Because...

It makes my lessons more meaningful (and hopefully will help my students retain the information better).

8. My least favorite part of the workshop was...

Using the app vs. [website only because it was difficult to do on my phone, but I could have had the students use the iPads instead.]

Because...

9. My favorite lesson plans are...

I liked all of them—the O2 demo is easy to do & fun. I really liked the mapping activity because that’s something I’ve tried doing with my students before (I like the way you set it up better).

Because...

10. Any other comments?

Please do more workshops—this was great.
An Introduction to Climate Change + Ocean Acidification

Shannon Waters
Masters Candidate
Scripps Institution Of Oceanography
May 7, 2016
Internationally, the scientific community agrees that human activities, largely the burning of fossil fuels, is causing a rapid increase in the amount of carbon dioxide and other greenhouse gases that are contributing to climate change (see the Intergovernmental Panel on Climate Change’s Fifth Assessment Report for further details http://www.ipcc.ch/). Let’s explore the mechanisms behind climate change and the evidence that supports it.
The sun’s solar radiation waves bring heat to Earth. Gases in the Earth’s atmosphere trap some of that heat and re-radiate it back to Earth, while some is released to space. Without these gases in our atmosphere, the Earth would be a much colder place! So we need greenhouse gases in our atmosphere in order to have a habitable temperature on Earth. However, by burning fossil fuels, we are releasing very large amounts of carbon dioxide into the atmosphere, and that’s too much of a good thing. The result is that much more heat is trapped within Earth’s atmosphere, warming the global temperatures and altering climate. Much of that heat is taken up by our oceans. In fact, the oceans have taken up approximately 93% of heat trapped by the atmosphere since 1955 (Levitus et al 2012).

Further reading:
Eddebbar, Gallo, Linsmayer. 2015. The Oceans and the UNFCCC.
In 1958, a researcher at Scripps Institution of Oceanography named Charles David Keeling began measuring atmospheric carbon dioxide levels from Mauna Loa Observatory in Hawaii. In the first few years, Keeling observed seasonal increases and decreases in atmospheric carbon. In spring, as plants grew and bloomed, carbon dioxide levels decreased due to plants uptake of carbon dioxide during photosynthesis. In late fall and winter, carbon dioxide increased. Over time however, a trend emerged — atmospheric carbon dioxide levels have been steadily increasing in what has come to be known as the Keeling Curve. When Keeling began his observations, carbon dioxide levels were at around 315 ppm. Today, sixty years later, they have surpassed 400 ppm.
By analyzing ice core samples, scientists have developed a historical record of atmospheric carbon dioxide levels and we can compare our current levels to those dating back 400,000 years ago. For centuries, atmospheric carbon dioxide had never been above 300 ppm. As the graph clearly shows, we have far surpassed those levels now. Climate science is a very active part of academic research and there is a lot we have yet to explore.
One area of active research is how atmospheric warming will influence our oceans. We know that the ocean plays a major role in regulating Earth’s climate by absorbing much of the heat in Earth’s atmosphere, approximately 93% of atmospheric levels since 1955. With rising atmospheric temperatures, the ocean has continued to warm as well. The majority of that warming happens at the surface. The IPCC Fifth Assessment Report states that, “on a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 (0.09 to 0.13) °C per decade over the period 1971 to 2010. In areas like the tropics where ocean temperatures are already very warm, organisms like corals have a narrower range of tolerance for increased temperatures. As a result of this stress, some corals expel their symbiotic zooxanthellae, leading to coral bleaching. Without symbionts, these corals lose a major source of nutrients and food, which can add more stress to their physiology and further diminish their health often leading to death.
Another area of active research is ocean acidification. We know from the Keeling Curve that atmospheric levels of carbon dioxide are increasing. The ocean acts as a sink for soluble gases like carbon dioxide and actually takes up about a quarter of atmospheric CO2. We can see in the graph pictured that seawater pCO2 mimics that of atmospheric CO2 – as the atmospheric levels increase, so do the seawater levels of CO2. What we can also see in this graph, however, is that as seawater levels of carbon dioxide increase, the pH of seawater decreases. And a decrease of pH means a more acidic ocean. It’s important to note when talking about ocean acidification that the ocean is not an acid. The pH of seawater is an average of 8.1, which is still above the neutral level of pH 7. However, global seawater pH is decreasing, therefore trending towards a more acidic ocean environment.
What is actually happening at a chemical level? When carbon dioxide reacts with seawater, carbonic acid is formed and hydrogen ions are released. The release of hydrogen ions decreases seawater pH. Ocean acidification refers directly to this decrease in oceanic pH from the addition of CO2. Another consequence of the chemical reactions of CO2 in seawater is that there is a decrease in carbonate ions. Carbonate is a key component of calcium carbonate, which is what many shelled organisms like oysters, mussels, and some plankton use to build their shells.
Here at Scripps, we have a number of researchers and studies addressing ocean acidification, including ocean acidification impacts on coral reefs, mantis shrimp and red rock shrimp. While much more research is needed, one conclusion we can start to draw is that not all species will be affected in the same ways by ocean acidification. For example, in a recent Scripps study led by Jen Taylor, ocean acidification had an adverse effect on red rock shrimp, inhibiting their transparency, which is key to the red rock shrimp’s camouflage to avoid predators. On the other hand, Jen Taylor’s lab is also studying ocean acidification impacts on the mantis shrimp, which apparently is unaffected by ocean acidification. The Martz lab develops the technology and chemical sensors like the WavepHox, that help us measure changes in ocean chemistry. We’ll learn much more about the WavepHox later today.