Engaging Students in the Pacific and Beyond Using an Inquiry-Based Lesson in Ocean Acidification

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ABSTRACT

We present a hands-on, inquiry-based activity exploring how CO_2 input to seawater affects the skeletons of several species of reef-building corals and other marine organisms by testing for changes in pH and calcium ion concentrations. Originally developed to inspire and recruit high school students in the state of Hawaiʻi into the science, technology, engineering and mathematics (STEM) fields, we assessed the effectiveness of the activity through the responses of 380 high school students to a series of questions about ocean acidification both before and after guiding them through the inquiry-based activity. Our results show that students gain a better understanding of ocean acidification and the relevance of the geosciences to their daily lives after their participation in the activity. © *2013 National Association of Geoscience Teachers*. [DOI: 10.5408/12-390.1]

Key words: ocean chemistry, pH, calcium carbonate, coral, climate change

INTRODUCTION

Global climate change results from rapidly elevating atmospheric levels of greenhouse gases and is one of the most significant and pressing issues of our time (IPCC, 2007a; Gonzalez et al., 2010; Hoegh-Guldberg and Bruno, 2010). While CO_2 is a naturally occurring and biologically important gas, most scientists concur that anthropogenically generated carbon dioxide (CO_2) constitutes a major contributing greenhouse gas affecting modern climate change (Petit et al., 1999; Siegenthaler et al., 2005). Although scientists and the media have emphatically warned the public that climate change may lead to increased heat waves, drought, insect infestations, wildfires, sea-level rise, and coastal flooding (Karl et al., 2009), less attention has been given to the consequence of elevated atmospheric CO_2 on ocean acidification, which threatens life in the world's oceans (Hoegh-Guldberg and Bruno, 2010).

As ocean conditions become more acidic, reef-building corals and other calcifying marine organisms have more difficulty using dissolved calcium carbonate to build their skeletons (Orr et al., 2005; Jokiel et al., 2008). The consequences of ocean acidification, therefore, are particularly relevant to tropical coastal communities where the economic value of coral reef ecosystems is staggering. For example, coral reefs are estimated to be worth $360 million a year to Hawaiʻi's economy (Cesar and van Beukering, 2004) and have recently been valued by U.S. residents to be worth $33.57 billion per year (Bishop et al., 2011).

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This laboratory exercise immerses students in an inquiry-based activity exploring how CO_2 input to seawater affects the calcium carbonate skeletons of marine organisms by testing for changes in seawater pH and calcium ion concentrations. The exercise is also designed to promote interest in the science, technology, engineering, and mathematics (STEM) fields and improve proficiency in the scientific method and hypothesis testing in the geosciences. Although these exercises were originally developed to inspire and recruit high school students in the state of Hawaiʻi into the STEM fields, the activities are appropriate and relevant to high school and college students in any community.

TARGET POPULATION

This paper presents a guided place-based and inquiry-based activity focusing on the chemistry behind ocean acidification as well as its effect on marine organisms. By incorporating environmental, political, and community concerns into the curriculum, place-based instruction has been hailed as an important pedagogical model for maximizing student interest and performance, particularly in Hawaiʻi (Volk and Cheak, 2003; Smith, 2007; Wiener and Rivera, 2010; Rivera et al., 2013). In addition, we employ an inquiry-based approach (National Research Council, 1996, 2012) as a means of engaging our students because this strategy is often seen as an effective one for connecting, recruiting, and retaining students in the field (Abell, 1999; Schneider et al., 2002). Inquiry-based learning hails from the early traditions of project-based and experiential learning (Dewey, 1938), and it involves guiding students to actively construct their own knowledge rather than solely providing them with knowledge. Evidence supporting the benefits of inquiry-based instruction comes from both cognitive research (Greeno et al., 1996) as well as empirical research in the classroom (Hmelo-Silver et al., 2007). Furthermore, in addition to facilitating the acquisition of knowledge, inquiry-based instruction has been advocated by both the American Association for the Advancement of Science (1993) and the

National Research Council (1996, 2012) as being essential to science education in that it exposes students to the process through which our collective scientific knowledge develops (i.e., the scientific method) while giving them practical experience in "the wide range of approaches that are used to investigate, model, and explain the world."

The lesson we present here was originally developed as one of several outreach and education programs currently being implemented at the Hawai'i Institute of Marine Biology (HIMB), a research institution of the School of Ocean and Earth Science and Technology at the University of Hawai'i at Mānoa. The motivation behind these lesson plans was originally to increase ocean literacy and interest in marine biology research among high school students in the state of Hawai'i, but the issue of ocean acidification should likely have broad appeal. Furthermore, the lesson plan presented here is ideally geared towards high school chemistry, marine science, or geoscience classes, but we believe this can easily be modified for other levels of instruction as well.

LESSON PLAN AND METHODS

Here, we describe how to break the activity into three consecutive days. On the first day, instructors should be prepared to review basic concepts about pH with their students as well as lead them through some simple hands-on activities. On the second day, instructors should be prepared to offer a more in-depth lecture on climate change, ocean chemistry, and ocean acidification, thus providing students with the necessary background to formulate their own hypotheses about ocean acidification's effect on marine organisms. On the same day, students will set up experiments to examine changes in pH as a result of bubbling CO_2 directly into seawater, and to explore how this change in pH affects the release of calcium ions (Ca^{2+}) from seashells, coral skeletons (if available), carapaces, sand (if derived from carbonate sources), or any other calcium carbonate ($CaCO_3$) substance derived from marine organisms. On the third day, instructors should be prepared to lead their students through the scientific processes of data analysis and reporting. For this, we recommend that students summarize their data in the form of bar graphs indicating the pH level and calcium ion concentrations for each of their experiments. See the section on "Expected Results and Suggestions for Implementation" later herein for an example. Once all students have completed their graphs, they should be prepared to give a short 5 min presentation of their results to the class. Here, we also present typical results and potential explanations for erroneous results. Lastly, students should be asked to write up their experiment in a scientific paper format. Additional supporting materials for this lesson plan can also be found at: http://www2.hawaii.edu/~himbed/.

Day 1: Pilot Studies

Science Background for Students

To understand the process of acidification, we need to understand the concept of pH, and how pH is measured. Values of pH range between 1 and 14, with a pH of 7 being neutral. How acidic or basic a solution is depends on the relative concentrations of H^+ and OH^- ions present. If the concentration of H^+ ions is more than the concentration of OH^- ions, the solution is considered acidic (i.e., pH < 7). If the concentration of OH^- ions is more than the concentration of H^+ ions, then the solution is considered basic (i.e., pH > 7). If the concentrations of H^+ and OH^- ions are equal to one another, the solution is neutral (i.e., pH $= 7$).

Certain chemicals in solution function as buffering agents and, when properly mixed in a solution, cause the solution to resist changes in pH when exposed to acids or bases. This property of resisting changes in pH makes buffered solutions extremely useful in protecting sensitive equipment, dealing with chemical accidents, and even in balancing the internal processes of living things. In addition to salt, there are many dissolved chemicals that are present in seawater. The complex composition of the dissolved chemicals in seawater allows it to be able to withstand changes in pH, and seawater therefore acts as a buffer. The buffering capacity of seawater is one of the most important reasons why life on this planet evolved as we know it.

In all living systems on Earth, organisms have evolved mechanisms to maintain their internal pH. The maintenance of pH inside an organism within a very small and optimal range is crucial for basic biological processes such as breathing, heartbeats, brain activity, and photosynthesis to occur. Very low (strongly acidic) pH values also indicate that a solution can be highly reactive, as it contains a high concentration of free protons (H^+ ions) that are available to quickly and energetically react with other molecules. Alternatively, solutions that have very high (strongly basic) pH values are also highly reactive, as they have high concentrations of hydroxyl ions (OH^-), which are also readily available to react with other molecules. For these reasons, solutions at both ends of the pH spectrum are hazardous to living systems.

Class Activities

The first day of instruction involves two activities. First, students obtain the pH values of a variety of solutions that can be commonly found in households and determine which of them fall into pH ranges that can support living things. In the second activity, students will also examine the ability of certain solutions to act as a buffer and resist changes in pH. Instructors should be prepared to explain the concept of pH and how it is measured.

(1) What is the pH of my solution?

Materials

- Various household solutions (e.g., drinking water, soft drinks, juices, mouthwash, bleach, vinegar, cleaning solutions, etc.)
- pH test kit or test strips

Procedure

Instruct students to bring one solution from home (e.g., drinking water, soft drinks, juices, mouthwash, bleach, vinegar, cleaning solutions, etc.) for which they would like to determine the pH. Using pH test strips or test kits (generally purchased from your local aquarium store), they will measure various solutions that are common to the household. Both the test kits and test strips, however, have a limited range of pH units (4.5–10) that they can measure. If available, use electrode-based pH meters, because they tend to be more accurate and can measure beyond this range.

equation A	$H_2O + CO_2 \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^- \Leftrightarrow CO_3^{2-} + 2H^+$
equation B	$CO_2 + H_2O + CO_3^{2-} \Leftrightarrow 2HCO_3^-$
equation C	$CaCO_3 \Leftrightarrow Ca^{2+} + CO_3^{2-}$

FIGURE 1: Three chemical equations essential to hypothesizing how ocean acidification may affect certain marine organisms (see text for explanation).

Otherwise, test kits and test strips will suffice. Have students measure the pH of their respective solutions and record their results on a master data table that combines results for the entire class. Based on these results, have students conclude what range of pH values is supportive of living systems, and which of the pH values are hazardous.

(2) What is the buffering capacity of seawater?

Materials

- See Table I

Procedure

For this activity, students can either work individually or in groups. First, students should pour 60 mL of seawater, tap water, and distilled/deionized water into three separate beakers, measure the initial pH of each liquid, and record this information in a data table. Next, to create a source of CO_2 for this experiment, students should remove the cap from a soda bottle, poke a hole in the cap, push airline tubing through the hole, and seal tubing in the cap with a glue gun or duct tape. The instructor should then demonstrate to the students that while gently shaking the soda bottle, they can pinch the tubing to control the flow of CO_2 gas out of the soda bottle. After some practice in maintaining a constant air flow through the tubing, students can begin the addition of CO_2 to each of their beakers by positioning the end of the tubing in the bottom of each of the beakers one at a time. Using the stopwatch, students should bubble each solution for a set amount of time (e.g., 30 s) and again measure the pH. The length of time each sample is bubbled (e.g., 30 s), and the rate of bubbling (e.g., number of bubbles per second) should be as close to identical as possible between the beakers. If there has been a measurable pH change of at least 1 pH unit, the treatment is completed. However, if there has been no change of at least 1 pH unit, continue bubbling and measuring pH as necessary until a change of 1 pH unit is measured. Record the time it took for a change in pH to occur.

Day 2: Pilot Studies Inquiry-Based Experiments
Science Background for Students

The process of ocean acidification is the progressive decrease in the average pH of ocean waters caused by the excessive absorption of atmospheric CO_2. Over the last couple of decades, approximately 50% of the CO_2 produced by humans has remained in the atmosphere, approximately 20% has been taken up by terrestrial ecosystems such as forests, while approximately 30% has been absorbed by the oceans (Sabine et al., 2004). These numbers suggest that the effects of climate change would likely be much more severe if the oceans were not able to absorb CO_2 and act as a global buffer. Unfortunately, the ability of Earth's oceans to absorb excess atmospheric CO_2 is finite, and we are quickly approaching their buffering capacity limits (Sarmiento et al., 1995).

The process of acidification of the oceans is already negatively affecting ocean chemistry. Since the beginning of the Industrial Revolution, average surface pH readings in the oceans have decreased by about 0.1 pH units (remember that the units on a pH scale are logarithmic, so a 0.1 pH unit decrease is equivalent to about a 30% increase in H^+ ions). Currently, Earth's atmospheric CO_2 concentration is about 380 parts per million (ppm). If current trends in anthropogenic CO_2 production continue, this value could easily double by the end of the century, resulting in a decrease in mean ocean pH of about 0.4 units from pre-industrial times (IPCC, 2007b).

What are the consequences of these changes in seawater chemistry on marine organisms? The short answer is that the long-term effects of ocean acidification on marine ecosystems remain difficult to predict (Atkinson and Cuet, 2008). Most studies, however, predict that ocean acidification will have overall detrimental effects on marine organisms and ecosystems, and specifically on coral reefs (Orr et al., 2005; Jokiel et al., 2008). What scientists have known for years (Broecker and Peng, 1979), however, is that ocean acidification leads to a decrease in the availability of carbonate ions (CO_3^{2-}), which are a crucial element in the formation of the shells and skeletons of a number of calcifying marine organisms such as corals, calcareous marine plankton, and mollusks. Under current conditions, the surface of the ocean is considered to be supersaturated with calcium carbonate (i.e., the amount of calcium carbonate dissolved in seawater exceeds the threshold of saturation, thus allowing for the formation of solid mineral calcium carbonate). In this situation, calcifying organisms such as reef-building corals are able to utilize carbonate from seawater and deposit it in their skeletons by forming calcium carbonate ($CaCO_3$). As additional CO_2 begins to dissolve into the ocean, however, the equilibrium (Fig. 1: Eq. A) between carbonic acid (H_2CO_3), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}) is pushed to the right, causing an increase in H^+, and thus a decrease in pH. As the pH of the oceans becomes more acidic, however, carbonate is converted to bicarbonate (Fig. 1: Eq. B). As a result, seawater is no longer supersaturated with calcium carbonate, causing solid forms of this mineral to dissolve (Fig. 1: Eq. C). In other words, the dissolution of calcium carbonate materials is not a direct result of acidification (i.e., the increased concentration of H^+) per se, but a result of the reduction of carbonate ions, ultimately causing calcium carbonate materials to dissolve.

This in turn can be detected as an increase in calcium ion concentrations in the seawater. The decline or possible eventual loss of coral reefs and other important marine ecosystems due to increasing global temperatures and atmospheric CO_2 concentrations is a serious concern.

Class Activities

On the second day of instruction, students will simulate the process of ocean acidification by bubbling 100% CO_2 gas into seawater and observe how this may affect certain marine organisms by monitoring for changes in pH as well as calcium ion concentrations. Instructors should provide a selection of experimental items including shells, coral skeletons, crustacean carapaces, sea urchin tests, plankton samples, and/or sand to choose from. Instructors should also be prepared to give a lecture on the chemistry behind ocean acidification as described above.

Guiding Questions

First, the pH levels being projected for the future should be emphasized to the students so that their experiments have more realistic value. According to the Intergovernmental Panel on Climate Change (IPCC, 2007b), a 0.4 decrease in oceanic pH by the year 2100 can be expected under a "business as usual" scenario (i.e., a scenario assuming that policies are never implemented to address climate change). Next, once students have decided on an experimental item and a hypothesis, they should be guided through the process of experimental design. All hypotheses require an appropriate test (treatment: CO_2) and control (treatment: no CO_2) experiment. In addition, students should be reminded that in order to test their hypothesis, they should monitor both their test and control experiments for changes in pH (using the pH test strips) and calcium concentration (using the calcium test kits) both before and after the addition of CO_2 to the test experiment. Each experiment should contain a minimum of 5 g of whichever substance (e.g., coral skeletons, shells, urchin tests, etc.) they would like to test and about 40 mL of seawater (i.e., enough to fully submerge the 5 g of material while also accounting for the water that must be sampled for measuring calcium concentration). Finally, the instructor should suggest to students that an incubation period of approximately 30 min, as described next, will likely be necessary before they will begin to observe changes in seawater chemistry.

Next, we present a series of questions that can be provided to students to stimulate ideas about different hypotheses and experiments they can perform. Encourage students to think about the ways in which different organisms may be affected by ocean acidification (e.g., will only those with calcium carbonate skeletons be affected?) and the ways in which you can detect this effect based on changes in the chemistry of the seawater (i.e., can dissolved calcium carbonate be detected by noticing an increase in calcium ion concentrations in the seawater?).

- What do you expect to happen to the pH of the seawater after the addition of CO_2 and how will this affect the experimental items in the seawater?
- Are all of the experimental items provided by your instructor made of calcium carbonate?
- Would the length of time each item was exposed to acidified water affect the results?
- Do different species respond differently?
- Does the morphology of the species matter?
- Why is it important to maintain a constant flow of CO_2 gas during the experiment?
- Is this experiment biologically relevant? Is a drop in 0.5 pH units likely in the next 100 y? What about 1 pH unit?

Example Procedure

The hypothesis and experiment described here may be provided to students as a guide, but since this is an inquiry-based activity, students should be reminded to come up with their own. The example provided here is a rather simple one, but it may also be possible to test more complex hypotheses. For example, students could compare how different species or different morphologies among the same species (e.g., corals) might be affected by ocean acidification. Alternatively, students could compare the results of using various levels of pH changes.

Example Hypothesis

If coral skeletons are exposed to acidified seawater (0.5 pH units lower than normal) for 30 min, the concentration of calcium ions in the surrounding seawater will increase.

Example Experiment

1. Place 5 g of coral skeletons from the same species in each of two separate 60 mL glass jars. Using a pipette, fill both jars with 40 mL of seawater.
2. Label jar one as "Control Experiment." This jar will not be exposed to CO_2 gas. Label the jar two as "Test Experiment." This jar will be exposed to CO_2 gas.
3. Measure the pH (using the pH test strips) and calcium concentration (following the instructions for the calcium test kits) of the water in both jars, and record these values.
4. Begin a constant flow of 100% CO_2 gas from the regulator through a piece of airline tubing. Place the end of the airline tubing in the bottom of the test experiment jar such that bubbles of gas rise from the bottom to the top of the jar through the seawater. Allow the CO_2 gas to bubble for 30 s. (Important: The flow rate of the gas must remain constant throughout the experiment.)
5. Take another pH measurement of the test experiment. If the pH has decreased by 0.5 pH units, begin the incubation period by sealing both jars with a lid. If the pH has not changed 0.5 pH units, continue bubbling the test experiments with CO_2 gas as necessary.
6. Allow both jars to incubate at room temperature for 30 min.
7. After the incubation period, remove the lids and again record the pH of the seawater in both jars. Follow the instructions of the calcium ion test kit, and measure the calcium ion concentration of the seawater in both jars.

Day 3: Data Analysis and Discussion

Instructors should begin class with a general discussion of the students' experience conducting the experiments. Students can then be guided through the process of generating graphs of their data, which they will share and discuss with the class. Instructors can stimulate collaborative discussion by encouraging student research groups to discuss their findings with each other. Finally, as homework, students should be asked to produce an in-depth laboratory report on their findings. Next, we present some guiding questions for both the class discussion and written report:

- What was difficult about planning or setting up your experiments?
- Did CO_2 gas lower the pH of seawater?
- Was this change in pH enough to cause the dissolution of calcium carbonate from your experimental items into the surrounding water?
- Were your hypotheses supported by the data? How do your data compare with other research groups in your class?
- Do your findings influence the way you view the ocean?
- Will this experiment change your behavior in terms of reducing your carbon footprint?
- What new questions do you have now that you have completed your experiment? What might you do differently next time?

EXPECTED RESULTS AND SUGGESTIONS FOR IMPLEMENTATION

Successful implementation of these activities will depend on the familiarity of the instructor with the pH and calcium ion test kits available to them. As with all experiments, instructors should emphasize to their students the importance of attention to detail and laboratory technique. In particular, the measurement of water to be placed in each experimental jar as well as the amount of water used for the calcium ion test kits should be done with as much precision as possible. Using inconsistent volumes of water will cause a major source of error.

In teaching these classes to our students, we have the most familiarity with using pH test strips from EMD Chemicals, Inc., and calcium ion test kits from Mars Fishcare, Inc. With regards to measuring pH, it is very important to be consistent with the timing of reading the pH test strips. This will ensure that each solution is given the same amount of time to produce the color change. On the other hand, electrode-based pH meters produce more precise and accurate readings, and if available, should be used instead.

The calcium ion test kits we use are based on colorimetric titrations that require adding drop-wise amounts of solutions provided by the kits to cause a color change in the water sample. The number of drops required to produce this color change is then translated to a calcium ion concentration. In our experience, however, different individuals may come up with slightly varying results, likely as a result of having different drop sizes. If students are working in groups, we therefore recommend that the same student perform the calcium ion concentration measurements throughout the experiment.

Here are some example student results and interpretations:

Day 1: Pilot Studies

(1) What is the pH of my solution? See Table II for a list of common household solutions and their expected pH.

(2) What is the buffering capacity of seawater?

If the rate of bubbling remained relatively constant between the different samples, the time required to cause a change of 1 pH unit should be in the following order: deionized water < tap water < seawater. This demonstrates the role of dissolved minerals in increasing the buffering capacities of aqueous solutions and underscores the importance of buffered seawater to the planet's ecosystem.

Day 2: Inquiry-Based Experiments

Here, we interpret the results (Fig. 2) of the example experiment described earlier in which a student investigates how coral skeletons react to the addition of CO_2 into seawater by measuring changes in seawater pH and calcium ion concentration. These results are based on using 40 mL of seawater and approximately 5 g of coral skeleton. In addition, 100% CO_2 was added to each experiment at a rate of ~3 bubbles per second for approximately 1 min. Seawater pH and calcium concentration were tested both before the addition of CO_2 ($t = 0$) and 30 min later. It is clear from Fig. 2A that the addition of CO_2 caused a decrease in pH. Next, Fig. 2B shows how acidification due to the addition of CO_2 affected the coral skeleton. Consumption of carbonate (Fig. 1: Eq. B) causes the dissolution of the coral's calcium carbonate ($CaCO_3$) skeleton, resulting in an increase in seawater calcium ion concentration. Note that slight increases in calcium ion concentration may be observed even without the addition of CO_2, indicating that current conditions in seawater may already be acidic enough to cause the dissolution of calcium carbonate skeletons. During the class discussion of results, teachers should again emphasize that pH changes of 1 unit or more are an extreme scenario. Students should be reminded that the pH scale is in fact a logarithmic scale, and that even small decreases in pH translate to orders-of-magnitude increases in dissolved H^+ ions. Lastly, it should be discussed with students that the conclusions they draw as part of this activity are based on experimenting with the skeletons of dead organisms. How ocean acidification will affect live organisms is a much larger debate that needs to factor in the ability of species to evolve and adapt to changing conditions.

VALIDITY AND IMPLICATIONS

We believe the strength of this laboratory exercise, and inquiry-based investigations in general, is that it more closely approximates authentic scientific investigation through the use of hypothesis testing and the scientific method. We do, however, recognize the difficulties of employing inquiry-based instruction in the classroom due to time, motivational, and organizational limitations of the student, as well as the practical limitations of implementation within the traditional learning environment (Edelson et al., 1999). This lesson plan, however, can be easily converted to a more traditional instruction model simply by providing students with the included example procedure and more directed guidance.

Originally, this lesson plan was developed for high school students in the state of Hawai'i. At the time of this article's publication, we have taught this lesson to 16 classes

TABLE I: Materials for Day 2.

Materials
• 200 g electronic scale (accurate to 1 g)
• 60 mL glass jars with lids
• CO_2 bulk tank with regulator (if unavailable, a similar setup can be accomplished using a bottle of carbonated soda as described for the Day 1 activity)
• Airline tubing
• Small skeletal fragments of different species of coral
• Various shells
• Various carapaces of marine crustaceans
• Sea urchin tests
• Plankton samples
• Sand
• Seawater
• Ca^{2+} test kits
• pH test strips (4.5–10) or pH meter (0–14)
• Stopwatch or timer
• 10 mL glass pipette with pipetting ball
• 1 L glass beakers
• Gloves

(380 students) visiting HIMB. While it is too soon to report on long-term studies on our ability to inspire local high school students to pursue undergraduate- or graduate-level studies in the STEM fields, we can at least relay our short-term observations. Both before and after the inquiry-based experiments, we collected data on high school students' knowledge on the subject of ocean acidification as well as their understanding of hypothesis testing. Our compiled data of 380 students (Fig. 3) show increases in the number of students selecting the correct answers for questions related to ocean acidification (Figs. 3A–3D), as well as hypothesis formulation (Fig. 3E). This is encouraging because it indicates that our inquiry-based approach not only results in an increased understanding of the science behind ocean acidification, but also a better grasp of the scientific process.

Furthermore, in comparison to other lesson plans that also focus on ocean chemistry, ours is unique because it focuses on slight experimental manipulations. For example, other unpublished lesson plans advocate the use of diluted HCl or acetic acid in experimenting on the effects of acidity on calcium carbonate, often resulting in its immediate dissolution. While dramatic, these exaggerated findings hide the subtleties and conflicting results often encountered in scientific research. The success of our approach (Fig. 3), therefore, indicates that encouraging students to make small pH changes that are in line with future predictions of ocean acidification still results in an improvement of students' grasp of this knowledge while also adding more realistic and predictive value to their experiments. Furthermore, this more closely mirrors how research in this field is actually performed. In our experience teaching this laboratory exercise, discussions of experimental error and unexpected results are common and often lead to a deeper understand-

TABLE II: A list of common household items and their expected pH.

Item	pH
	1
Lime juice or Coca-Cola® (fresh)	2
Vinegar, Coca-Cola® (flat), or apple juice	3
Tomatoes	4
Coffee or yogurt	5
Sugar water, tap water[1], or human saliva	6
Tap water	7
Baking soda dissolved in water, tap water, or eggs	8
Bleach	9
Window cleaner	10
Ammonia	11
Dishwasher detergent	12
	13
	14

[1]Note that the pH of tap water may range between ~6 and ~8, depending on the presence of dissolved minerals.

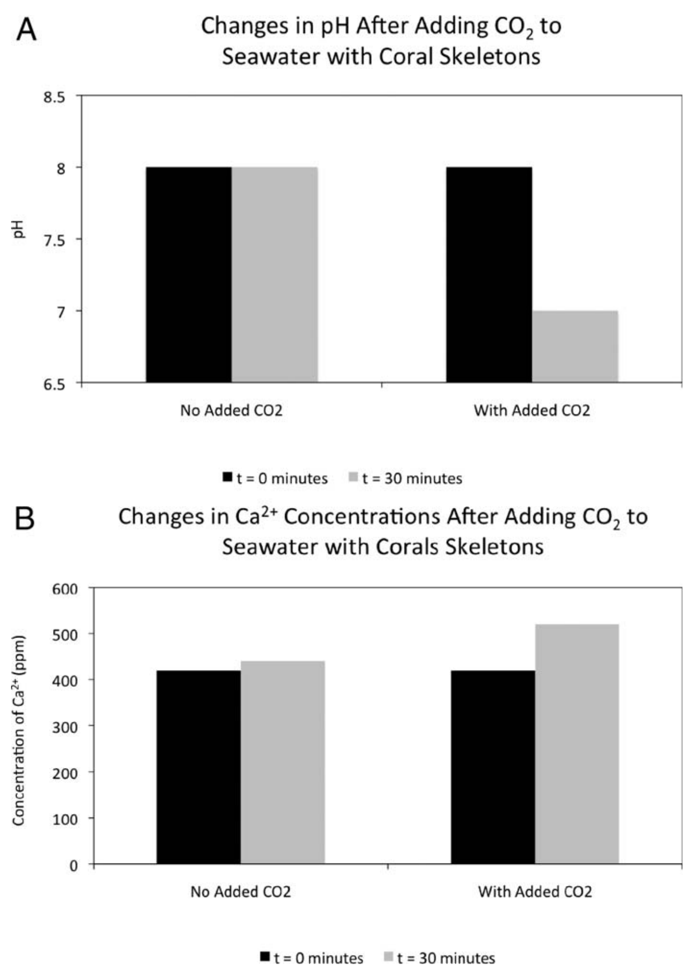

FIGURE 2: Example data showing changes in (A) pH and (B) calcium ion concentration after adding CO_2 to seawater with corals skeletons.

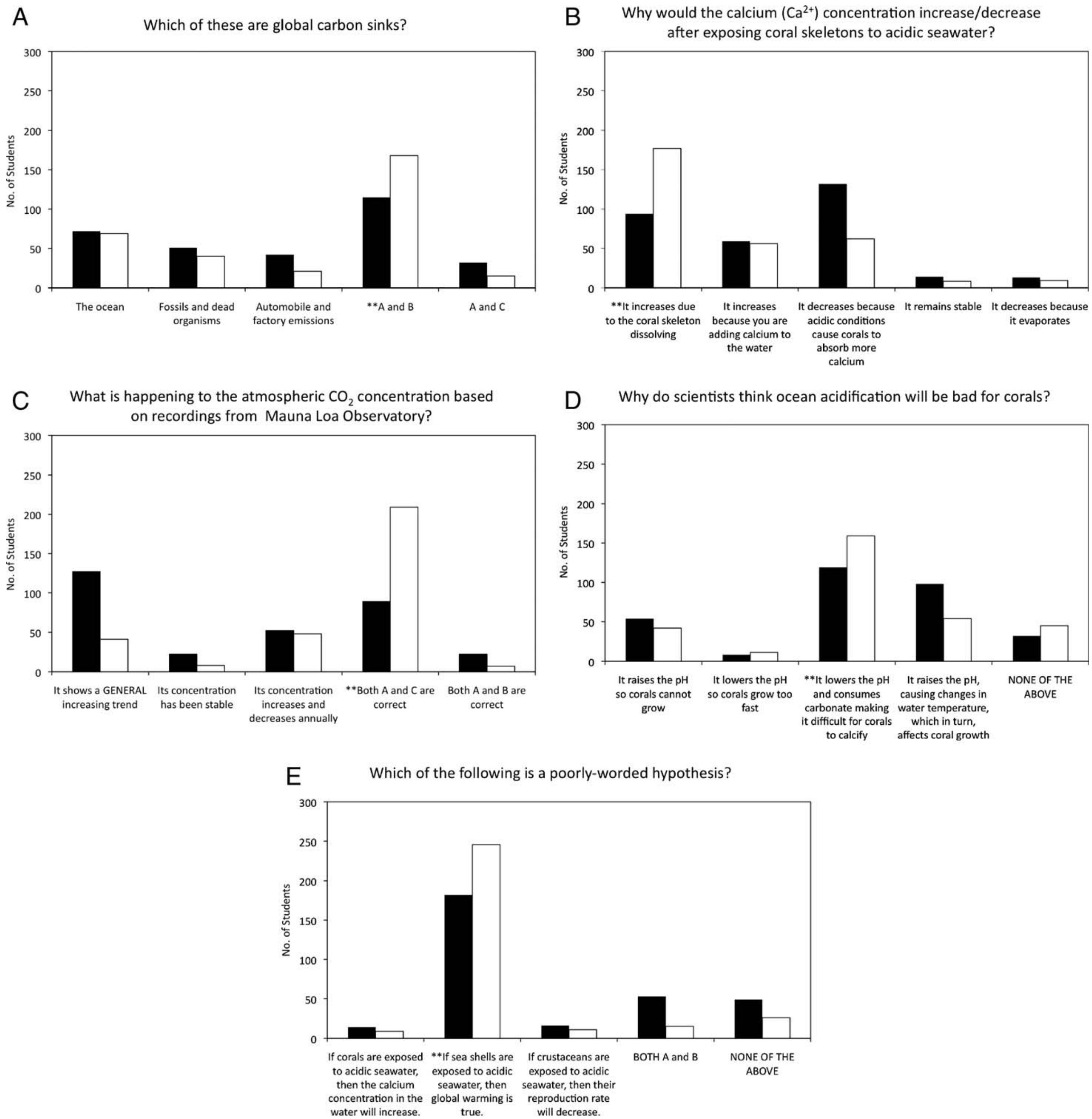

FIGURE 3: Compiled data from 380 high school students indicating their responses to each of four multiple-choice questions related to the topic of ocean acidification (A–D) as well as a question about hypothesis formulation (E). Each graph shows the number of students that selected each potential response both before (black bars) and after (white bars) completing the inquiry-based experiment. ** indicates the correct response.

ing of the topic as well as the realities of scientific experimentation.

As part of our ongoing effort to increase interest in marine science research, we take students on a guided tour around our research facility to emphasize that research on this topic continues to be investigated by today's scientists. It is our hope that doing so provides the students with a sense of empowerment. Although they may not be professional scientists yet, they are still able to address similar research questions currently being pursued by many scientists today. This is another important aspect of our efforts, because while small island states and nations in the Pacific are particularly vulnerable to the consequences of climate change (e.g., endangered food security, rising sea levels, etc.), Pacific

Islanders continue to be underrepresented in the geosciences (Gibson and Puniwai, 2006; Huntoon and Lane, 2007). This knowledge and empowerment gap places them at a disadvantage in terms of their ability to confront climate change issues, and thus underscores the importance of continuing to inspire Pacific Islander students to pursue careers in the geosciences.

The effects of climate change, however, will be felt beyond the Pacific. Despite increasing media coverage, the general public continues to remain relatively unconcerned and uninformed (Boykoff and Boykoff, 2007; Kellstedt et al., 2008). On the other hand, research on ocean acidification, which is just one of many consequences of increasing greenhouse gases, is still arguably in its infancy. As a result, communicating the specifics of this technical information to the general public will likely be even more difficult (Fauville et al., 2012). Increasing the literacy of our students, however, is an important grassroots effort towards creating an informed public better able to address these issues on a policy level.

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