Title
Losing Base: Education and Changing Ocean Chemistry

Author
Bowman, Amy

Publication Date
2014-04-01

Losing Base:

Education and Changing Ocean Chemistry

Amy Bowman

Center for Marine Biodiversity and Conservation
The Scripps Institution of Oceanography
May 30, 2014

Table of Contents

Committee Signature Page: iii
Abstract 1
Introduction 2
Past Climate Change Events 3
Possible Future Scenarios 5
The Ocean's Role in the Economy 7
Three Policies for Reducing Emissions 8
Why Emission Reductions Policies Have Been Unsuccessful 9
Education as a Tool for Mitigation 11
Modalities of Learning 12
The Project 13
Methods 15
Results 16
Discussion/Conclusion 18
References 20
Existing Videos 24
Appendix A 25
Appendix B 28
Appendix C 30

Capstone Advisory Committee Final Capstone Project Signature Form

Losing Base: Education and Changing Ocean Chemistry

Amy Bowman

Spring 2014
MAS Marine Biodiversity and Conservation
Capstone Project

Capstone Advisory Committee

Dr. Andreas Andersson, chair, Assistant Professor, Scripps Institution of Oceanography

Signature:______________________________________ Date:____________________

Email:______________________________________ Phone:____________________

Kristin Evans, Education Director, The Birch Aquarium

Signature:______________________________________ Date:____________________

Email:______________________________________ Phone:____________________

Lauren Linsmayer, PhD Student, Scripps Institution of Oceanography

Signature:______________________________________ Date:____________________

Email:______________________________________ Phone:____________________

Emily Gottlieb, MAS, MBC, Scripps Institution of Oceanography

Signature:______________________________________ Date:____________________

Email:______________________________________ Phone:____________________

Photo Courtesy of James Begeman

Amy Bowman
MAS Marine Biodiversity and Conservation
Spring 2014

Losing Base:

Education and Changing Ocean Chemistry

Abstract:

Humans are causing a shift in ocean carbonate chemistry largely due to a heavy reliance on fossil fuels as an energy source. The ocean absorbs approximately one quarter of the carbon dioxide (CO_2) that humans emit into the atmosphere every year. While atmospheric CO_2 levels have varied through natural forcings in the past, the rate of increase his likely not been as rapid as that experienced since the Industrial Revolution; a change that is attributable to human activities (Canadell *et al.* 2007). High levels of atmospheric CO_2 emissions lead to the acidification of the ocean as well as driving lower seawater saturation levels of aragonite (Ω_{Arag}), a polymorph of calcium carbonate ($CaCO_3$) necessary for marine calcifying organisms. The effects of ocean acidification (OA), sometimes termed "the other CO_2 problem", on individual marine organisms have been analyzed to show that many species, especially marine calcifiers, can be affected. As ocean ecosystems are highly interconnected through complex food web dynamics, OA could cause ecosystem-wide consequences from these individual species impacts. As humans get approximately 20% of the worldwide protein from the sea, changes in resource availability from OA could impact us negatively. The ocean is considered a public good from the stance of economic policy, so addressing ocean acidification has been unsuccessful because nobody wants to pay the price of pollution. Because economic policy has not succeeded, education should become a larger focus for adaptation and mitigation of OA. In order to maximize the effectiveness of education, it is important to understand that not everyone benefits from the same modality of learning. A common study on the modalities of learning is referred to as VARK, which is an acronym for Visual, Aural, Reading/Writing, and Kinesthetic (Fleming 2001). Because video can incorporate multiple modalities of learning, it has become widely utilized as a mainstream teaching tool, especially when incorporated within a lesson plan that involves writing and hands-on activities. Based on these findings and research, I created a 21-minute documentary-style video for a middle-school target audience. A survey ("quiz") was also created to accompany the video. Initial survey results from 235 middle-school students in test classrooms located both in Hawaii and California showed content knowledge improved by 21.3% after watching the video and children's self-reported knowledge about OA changed from mostly never having heard the term to feeling confident in having some knowledge.

Introduction:

Ocean acidification (OA), which increases with rising atmospheric carbon dioxide (CO_2) levels, is a global issue. The ocean performs many ecosystem services, including the absorption of about one quarter of all of the CO_2 humans emit into the atmosphere (Le Quéré *et al.* 2009). When CO_2 comes into contact with ocean water, carbonic acid (H_2CO_3) is created (Fig. 1). H_2CO_3 breaks down further into bicarbonate ions (HCO_3^-) and hydrogen ions (H^+). This increase in hydrogen ions lowers the pH of the ocean (Caldeira and Wicket 2003). The average pH of the ocean was estimated to be approximately 8.2 at the beginning of the Industrial Revolution and has currently dropped to approximately 8.1. It is predicted to decrease by another 0.2 to 0.3 pH units by the year 2100; it will continue to decrease even if we stabilize our CO_2 emissions immediately (NRC 2010). While a drop of about 0.1 may not seem large, pH is on a logarithmic scale. In fact, pH is the negative logarithm of the hydrogen ion concentration of a solution, so a 0.1 change represents approximately a 30% increase in the acidity of the ocean. While ocean pH is basic at 8.1, because the direction of the reaction is towards acidity, it is called an acidification reaction (Allen 2011).

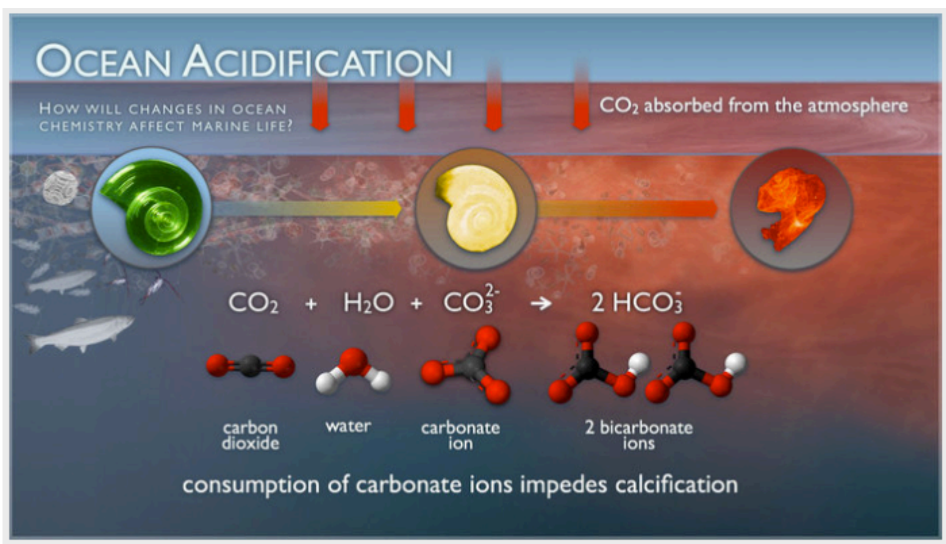

Fig. 1. Illustrates the chemical reaction of atmospheric carbon dioxide with seawater. (Image from NOAA, n.d.)

Carbon dioxide is a naturally occurring gas in the atmosphere. It is part of the Earth's carbon cycle that circulates carbon between the earth, ocean, plants, animals, and inorganic compounds like soil and sediments. Humans have been burning fossil fuels to create energy since the Industrial Revolution, which results in the release of CO_2 into the atmosphere. This disrupts the natural carbon cycle (EPA 2013). Human generated CO_2 emissions have continued to increase rapidly, even after the discovery of the potentially negative impacts this could have on the planet. The concentration of CO_2 in the atmosphere may even increase at a rate that is two orders of magnitude faster than the rates the planet has seen in the past 650,000 years (Royer 2005).

OA results in decreasing seawater carbonate ion (CO_3^{2-}) saturation. As CO_3^{2-} is a building block necessary for marine calcifying organisms to build shells and exoskeletons, a lower availability of this resource can lead to difficulties in building these structures (Waldbusser *et al.*2013). Corals, calcifying algae, and pteropods have all been identified as susceptible to the effects of OA, as have some echinoderms and crustaceans. Of particular concern to many is the shellfish fishery due to the reduced success in fertilization and recruitment observed in benthic invertebrates such as oysters, clams, and mussels under conditions of OA (Rodolfo-Metalpa *et al.* 2011). If some calcifying organisms become less capable of creating exoskeletons and shells in more acidic water (Ries 2011), this could have impacts that cascade through the food web (Raven *et al.* 2005). Humans get approximately 20%, of worldwide protein from the ocean (Barry 2013); changes in the food web could negatively impact the economy.

Climate Change and the Past:

To better understand future implications for marine ecosystems, it is important to review past climate conditions; the fossil record, deep-sea sediments, and ice-core samples all provide evidence of climate change in the earth's past. Since assessing the future impacts of OA is difficult in lab settings, due to the lab's limited environmental complexity and the shortened timeframe of experiments, it can be helpful to study past geologic events; we can study how the Earth's environmental system was affected over geologic timescales during previous events. Studying the past may assist us in evaluating solutions for the future. While past OA, and climate change, events were not identical to current climate change, similarities do exist that can assist us by acting as analogues for assessing future implications (Norris *et al.* 2014).

In comparing past and present atmospheric conditions, one must consider the timescale of CO_2 emissions. While some events in our planet's geologic past - like the Aptian Oceanic Anoxic Event (Méhay *et al.* 2009), the Triassic/Jurassic boundary (Hönisch *et al.* 2012), and the End-Permian and Cretaceous-Tertiary boundary (Hönisch *et al.* 2012), - could represent possible analogs to present atmospheric CO_2 concentrations, CO_2 was not released in a rapid pulse similar to current conditions. In short, humans have emitted more carbon dioxide into the atmosphere in a shorter timeframe than this planet has experienced previously (Zeebe *et al.* 2008).

The closest analogue from past conditions is the Paleocene-Eocene Thermal Maximum (PETM). During that time, there were significant increases in surface temperatures, substantial carbon release, and OA. The onset of the PETM occurred in approximately 80 thousand years (Farley and Eltgroth 2003); this means that on a geologic timeframe, the changes in the PETM happened very rapidly (Zeebe *et al.* 2008). However, there were some pretty major differences from current climate conditions including the lack of polar ice, the different configuration of the continents, and a different base climate. Nonetheless, it is the closest event on record that compares to modern times (Goodwin *et al.* 2009). "This event is recognized as one of the four major metazoan reef crises of the past 300 My" (Hönisch *et al.* 2012). Since a major crisis happened during the PETM, the closest analog to current climate change, the possibility exists that such a metazoan reef crisis could happen in the future should carbon dioxide emissions continue to increase.

Using information from the past to analyze current conditions, we may be able to quantify changes in ocean chemistry and biological response. Current survey information will need to be combined with modeling in order to help with future predictions. While fluctuations have occurred in our geologic past, previous ocean chemistry conditions were fairly stable when compared with the model projections of the future. As our current input rate exceeds prior input rates, we could infer that changes could occur more rapidly than those previously seen (Hönisch *et al.* 2012). Looking at geologic records can show us how our planet has responded to previous changes in climate and may be able to help us understand possible future scenarios.

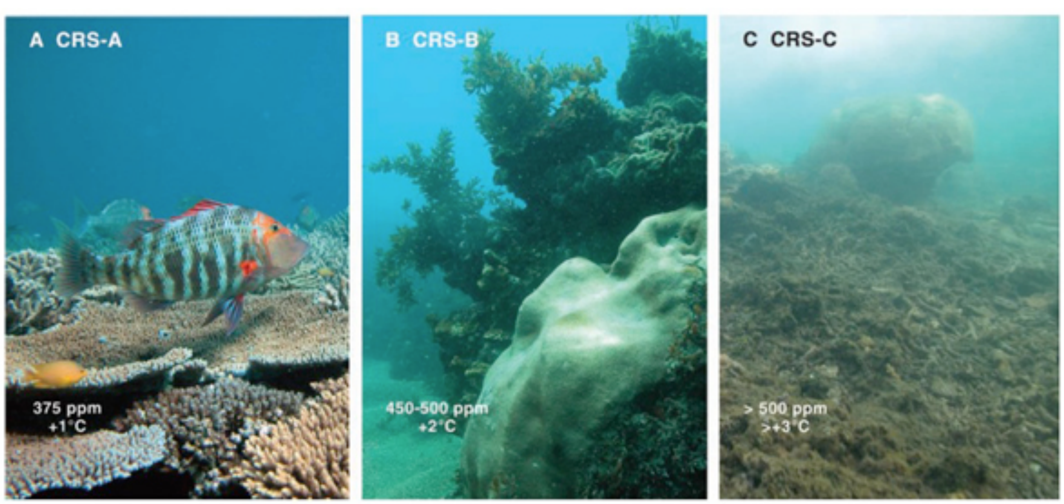

Fig. 2. Shows examples of Australian reefs used as analogues for three different future emissions scenatios with increased temperatures atmospheric CO_2 (Photos by O. Hoegh-Guldberg 2009)

OA Possible Future Scenarios:

Several emissions scenarios give us the possible ranges for our potential future. While scenario-based projections are not literal predictions of the future - there is no climate change crystal ball - they can be useful tools. The International Panel on Climate Change (IPCC) Special Report on Emissions Scenarios gives four different projections. The A scenarios are less ecologically friendly, while the B scenarios are more ecologically friendly. These are further divided into 1 scenarios where the future has lower emissions, than the 2 scenarios where the future has higher emissions. According to the IPCC, B1 is the lowest likely range and A2 is the highest likely range, with B2 and A1 falling somewhere in-between (IPCC 2007). Under all future scenarios in which atmospheric CO_2 increases, ocean acidification will intensify.

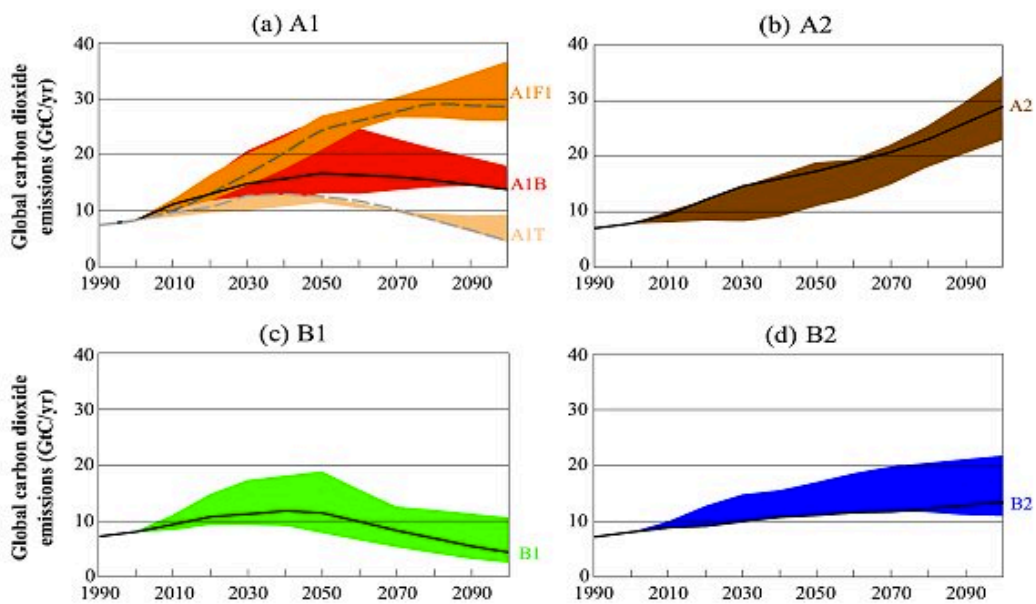

Fig. 3: "Total global annual CO2 emissions from all sources (energy, industry, and land-use change) from 1990 to 2100 (in gigatonnes of carbon (GtC/yr) for the families and six scenario groups. The 40 SRES scenarios are presented by the four families (A1, A2, B1, and B2) and six scenario groups: the fossil-intensive A1FI (comprising the high-coal and high-oil-and-gas scenarios), the predominantly non-fossil fuel A1T, the balanced A1B in Figure SPM-3a; A2 in Figure SPM-3b; B1 in Figure SPM-3c, and B2 in Figure SPM-3d. Each colored emission band shows the range of harmonized and non-harmonized scenarios within each group. For each of the six scenario groups an illustrative scenario is provided, including the four illustrative marker scenarios (A1, A2, B1, B2, solid lines) and two illustrative scenarios for A1FI and A1T (dashed lines)". (Data from IPCC 2007)

Figure 3 shows that cumulative CO_2 emissions projections for the year 2100 range from 370 gigatons of carbon (Gt C), should strict mitigation procedures be implemented, up to 1930

Gt C, should we choose not to change our consumption of fossil fuels (Orr *et al.* 2005). This translates to a range of greenhouse gas emissions that could increase anywhere between 70 to 250% by 2100 when compared to 2000 levels. Higher levels of atmospheric CO_2 will cause further changes in ocean carbonate chemistry (Orr *et al.* 2005).

The average seawater calcite saturation state could decrease from a pre-industrial value of 3.7 to 3.4 - as in the B1 strict mitigation scenario - down to 1.8 - as in the A2 "business as usual" scenario (IPCC 2007). Stricter mitigation scenarios decisively lead to lower concentrations of atmospheric CO_2, less climate change, and less acidification of the ocean; this ultimately means more stability in the calcite saturation state, a benefit for marine calcifying organisms (IPCC 2007).

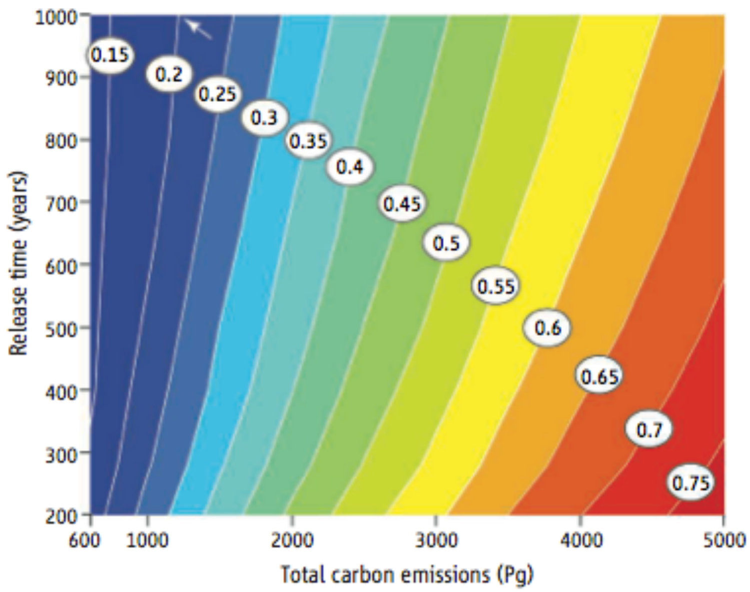

Fig. 4. Total carbon emissions by release time from a series of scenarios. (Data from Zeebe et al. 2008).

"To avoid a surface ocean pH decline by more than 0.2 units, total emission targets would have to range from ~700 Pg C over 200 years to ~1200 Pg C over 1000 years." If emissions can be reduced after the year 2050 and capped at 1500 Pg C, surface ocean pH would decline by ~0.35 units relative to preindustrial levels. The aragonite saturation state in the warm surface ocean would drop from ~3.5 to ~2.1 under this scenario." (Zeebe et al 2008). Figure 4 shows total carbon emissions over time and relative changes to pH. These projections show that lower emissions of CO_2 over time lead to less OA.

The Ocean's Role the Economy:

The ocean is a large contributor to the world economy. In the United States, 1/6 of jobs are ocean related, whether in fishing and boating, tourism and recreation, or shipping. "In 2009, the ocean economy, which includes six economic sectors that depend on the ocean and Great Lakes, contributed over $223 billion annually to the U.S. gross domestic product (GDP) and provided more than 2.6 million jobs" (NOAA 2013). Fishing is an extremely important economic contributor to many countries and supplies about 200 million jobs worldwide. About 100 million tons of fish are taken from the sea every year. Annual fishing revenues alone bring in approximately $75 billion worldwide (University of Michigan 2006). That figure does not account for the economic impacts of fisheries on boat manufacturing or the canning industries. If those figures were included, the total global value of the fishing industry would actually be closer to $240 billion annually (Dyck and Sumaila 2010).

Besides fishing and fisheries, another commodity likely to be affected by ocean acidification is coral reef tourism. If we look at coral reefs from a purely financial standpoint, the potential net benefits for the world are huge, provided that the reefs were healthy and well managed. A direct use value, reef tourism, is estimated at $9.6 billion annually (Cesar *et al.* 2003). However, indirect use values should also be taken into account as well. The protective function coral reefs provide as an ecosystem service are valued at $9 billion annually, while conservation and non-use values are an estimated $5.5 billion annually. Reefs are also valuable for medical and pharmaceutical research (Cesar *et al.* 2003).

Table 3: Potential net benefit streams per year and net present value (NPV) of coral reefs per region (in US$ million) [see note 3 for supporting calculations]

	Southeast Asia	Caribbean (ex. USA)	Indian Ocean	Pacific (ex USA)	Japan	USA	Australia	World
Reef area (km^2)	89,000	19,000	54,000	67,000	3,000	3,000	49,000	284,000
Fisheries	2,281	391	969	1,060	89	70	858	5,718
Coastal protection	5,047	720	1,595	579	268	172	629	9,009
Tourism/recreation	4,872	663	1,408	269	779	483	1,147	9,621
Biodiversity value	458	79	199	172	529	401	3,645	5,483
Total	12,658	1,853	4,171	2,079	1,665	1,126	6,278	29,830
NPV (at 3%)	338,348	49,527	111,484	55,584	44,500	30,097	167,819	797,359

Fig. 5. Potential net benefits of coral reefs per region in millions of US dollars. (Data from Cesar et al 2003)

Figure 5 shows that the ocean is a very large contributor to the world economy. While it would be extremely difficult to predict what the total financial loss associated with ocean acidification will be on the world's economy, it can be anticipated that a shifted food web and reduced coral reefs could cause revenues in both fishing and tourism to decline. Jobs will likely be lost, causing further stress to the economy. Ecosystem services provided by coral reefs, like shoreline protection, would potentially be impacted and could be associated with an additional economic loss. Other losses from the decline of coral reefs could include non-use values such as option values, bequest value, and existence value.

Three Policies for Reducing Emissions:

Direct regulation, sometimes called Command and Control, tends to be the least economically efficient method for controlling global carbon emissions, but they tend to be fairly popular amongst politicians. The government tells firms to adhere to a certain level of emissions they deem efficient or firms will face civil and/or criminal penalties (Jacobsen 2013). Some of the ways this policy can be implemented is to place limits on production, create a technology standard, or create a performance standard. The reason these tend to be less efficient than market-based solutions is that they usually cost more. Another drawback is that they do not promote technological innovations (Jacobsen 2013).

Taxes are generally unpopular with voters and firms. This is a reason that politicians maybe hesitant to use this market-based tool. Taxes require firms to internalize the cost of the marginal damages to the environment associated with production (Pizer 2002). This would raise the firm's costs from private marginal cost to social marginal cost and cause production to fall to an efficient level. The cost of the tax (Fig. 5) is generally passed on to the consumer, who will consume less of the good due to the higher price of the good with tax included (Jacobsen 2013).

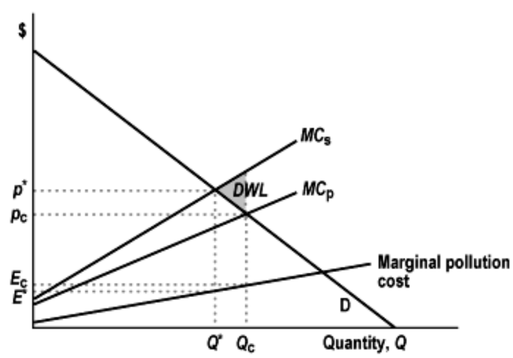

Fig. 6. Supply and Demand curve showing a cost from the marginal damages of pollution. (Data from Carlton and Perloff 2000)

Figure 7 illustrates that when a tax is implemented, quantity falls to the efficient level while price increases to the efficient level. Producers and consumers both experience surplus losses in this process, but the taxes collected could potentially be redistributed to offset this loss.

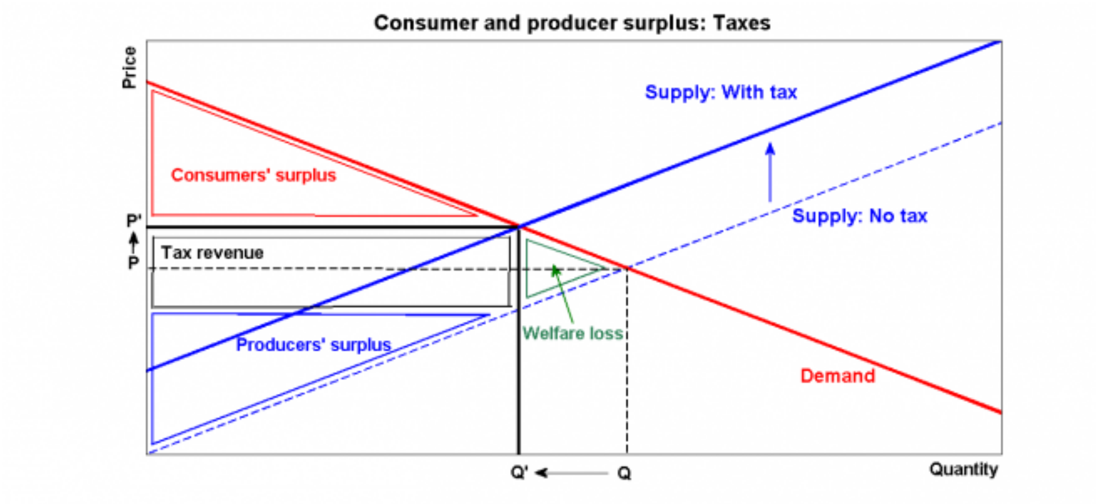

Fig. 7. Supply and Demand curve showing producer and consumer surplus in relation to taxes. (Data from Crampton 2012)

Tradable permits, another type of market-based regulation, tend to be more popular than direct taxes (Pizer 2002). In this scenario, the government limits the amount of permits it will sell to allow producers to emit carbon. Firms must have permits in order to emit or they will be punished in civil and/or criminal court. Firms may trade amongst themselves to buy or sell permits, creating a market, and therefore, a price for pollution. Allocating permits essentially gets to the same efficient level of emissions as a tax (Pizer 2002). A problem with tradable permits is that as they raise the cost of goods, politicians are again hesitant to implement these systems. Another drawback to tradable permits is that they can have associated administrative costs. They tend to be more popular than taxes, however, and could take us to the same efficient level as a tax (Jacobsen 2013).

Why Emission Reduction Policies have been Unsuccessful:

The ocean is considered a public good; it can be enjoyed by anyone, whether or not they pay to enjoy it. Ocean acidification is a collective action problem because the atmosphere and the ocean are both public goods. There are reciprocal externalities in this case. Everyone who emits CO_2, whether it is in the form of electricity, transportation, industry, or agriculture, places a negative externality on the rest of the planet and doesn't have to pay for their emissions. Because they pay nothing for our choice to burn fossil fuels, they lack a reason not to do so (Keohane and Olmstead 2007).

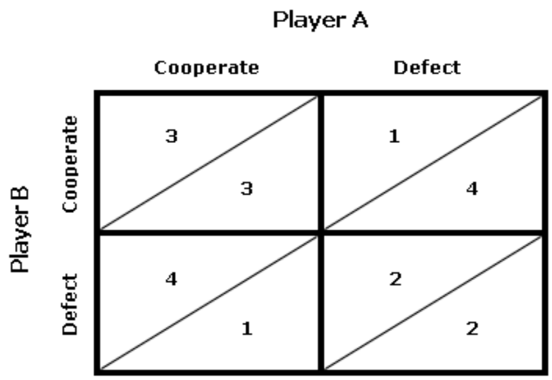

Fig. 8. Illustration of the Prisoner's Dilemma game showing that personal incentive for defecting is higher relative to cooperating. (Data from Smith 2003)

Game theory, in particular the Prisoner's Dilemma (Fig. 8), shows us that in trying to act in the individual's best interest taking others' actions as given, humans can collectively end up with worse outcomes than when they collaborate. Even though the problems associated with burning fossil fuels is known, fossil fuels are still burned (Gibbons 1997). While it is understood that everyone would collectively be better off as a whole to act in the collective best interest, each person, or country, has a financial incentive to free ride from the emissions reductions made by others. In order to attempt to gain the most financially, each player in the Prisoner's Dilemma plays to win, which is bad for both players overall. (Keohane and Olmstead 2007)

The Coase Theorem states "private bargaining will overcome negative externalities, without the need for government intervention, regardless of how property rights are allocated" (Keohane and Olmstead 2007). These assumptions fail in the case of OA policy for several reasons. One reason is that bargaining between emitters and victims is neither easy nor inexpensive. Plus, any deals would not be easy to enforce. The entire planet will be affected by current emissions, but will likely not feel the effects for many years, possibly even generations. Another reason for failure is that the transaction costs of mitigation will be high. For the Coase Theorem to work, transaction costs need to be negligible. In addition, causation is challenging to establish. Each emitter has a hand in creating the overall emissions; however, it is impossible to tell which molecules of CO_2 in the ocean were created at each firm (Keohane and Olmstead 2007).

One of the many problems seen today is that the wealthier countries, who have historically produced the most carbon emissions, are not the places that will be first affected by those same carbon emissions; the developing countries will see the most impacts earlier than developed countries (Barrett 1998). The nations of the world have so far been unable to agree upon a plan to reduce carbon emissions, largely do to financial and socio-economic reasons. Wealthier countries do not want to pay for the CO_2 they have already emitted, nor do they want to give financial support to developing countries. Developing countries would like to be supported in their National Appropriate Mitigation Actions (NAMAs) by wealthier countries in their efforts to reduce emissions. They argue that since they did not create the problem, they bear less responsibility for its resolution than do the wealthier countries (Kirby 2013).

The United Nations Framework Convention on Climate Change (UNFCCC) has tried to implement binding legislation to reduce carbon emissions, including the Kyoto Protocol of 1997. However, there are still members of the United Nations, including the United States, that have not ratified this treaty. In fact, Canada withdrew from the Kyoto Protocol last year (UNFCCC 2013). The Conferences of the Parties (COP) have been held around the world since 1995. The last meeting, COP-19, was held in Poland in the fall of 2013; the Polish government declared their intent to continue, and perhaps increase, their usage of coal as an energy source (Krukowska 2013). Getting every nation of the world to agree on how to reduce emissions is extremely difficult, and, as many countries feel it is not in their own best interest, has remained unsuccessful.

Education as a Tool for Mitigation:

Since policies to accomplish the reduction of greenhouse gas emissions have yet to succeed, even after two decades of negotiations, more focus should be placed on education. Children are actually more likely than adults to take action on climate change issues, specifically they are more likely to modify their own behaviors and engage in advocacy; many claim to be active in conservation already. While parents remain the household decision-makers, parents look to their children as great sources of environmental information and are likely to be influenced by their children's opinions. Parents make the decisions, but children help form the opinions of households (The Ocean Project 2009). Because of this, children could influence both the voting and purchasing decisions of their parents. By educating the youth of today, children are likely to change their own behaviors and positively influence the conservation decisions of their parents. Education can be an important component of coping with the difficult problem of attempting to reduce greenhouse gas emissions (Lenzen and Murray, 2001).

Teachers have the opportunity to help students understand how their lifestyle choices impact heat-trapping greenhouse gas emissions, including CO_2. Discussing personal energy consumption and the consumption of goods and services can assist children in making better environmental choices (Lenzen and Murray, 2001). More than 80% of students surveyed in South Australia believed that the solution to environmental problems depends on drastic lifestyle changes (Worsley and Skrzypiec, 1998). As children are more likely than adults to take action on climate change, if they are given the tools to understand their personal impacts, they are more likely to make lifestyle changes and influence their parents to make lifestyle changes that would reduce greenhouse gas emissions.

Ideally, climate change education should emphasize connections between students, their energy consumption, and climate change. If students are taught how their personal energy consumption influences global climate change, they are more likely to make lifestyle changes (Cordero et al 2008). One helpful tool that educators can use is a carbon footprint calculator. There are many available online designed for use by children; an age-appropriate calculator can be found at http://www.cooltheworld.com/kidscarboncalculator.php.

Giving children information and empowering them to make environmentally focused decisions has the potential to lead to behavioral changes for both the children and their parents. As economic policy has not been successful, education is an avenue that could potentially be utilized to reduce greenhouse gas emissions at a personal level. These individual changes could lead to a larger reduction in emissions overall.

Modalities of Learning:

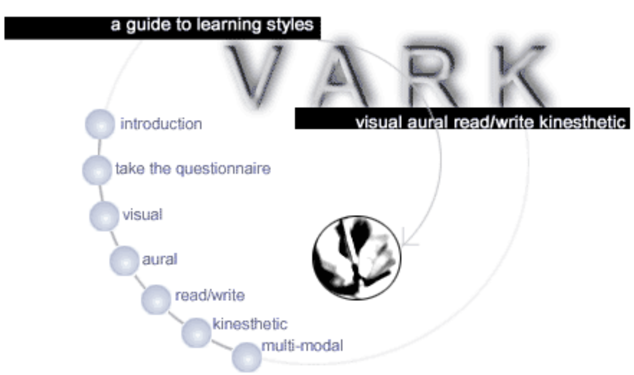

Fig. 9. Illustrates the VARK learning styles, which include Visual, Aural, Read/Write, Kinesthetic, and Multi-Modal. (Image from Fleming 2014)

Students have diverse preferred styles of learning (Fleming 2001). Several different models highlighting modalities of learning have been created over the last few decades. One of the most commonly used is called VARK. VARK is an acronym for Visual, Aural, Reading and Writing, and Kinesthetic. In addition to the four main styles covered by VARK, evidence also shows that many students are multi-modal, meaning that they learn best with a combination of two or more styles (Fleming 2001). Understanding how students prefer to learn and allows teachers to cater to students' different learning styles to ensure successful communication of important information.

According to the VARK model, "Visual learners prefer maps, charts, graphs, diagrams, brochures, flow charts, highlighters, different colors, pictures, word pictures, and different spatial arrangements. Aural learners like to explain new ideas to others, discuss topics with other students and their teachers, use a tape recorder, attend lectures and discussion groups, and use stories and jokes. Read/Write learners prefer lists, essays, reports, textbooks, definitions, printed handouts, readings, manuals, Web pages, and taking notes. Kinesthetic learners like field trips, trial and error, doing things to understand them, laboratories, recipes and solutions to problems, hands-on approaches, using their senses, and collections of samples" (Hawk and Shaw 2007).

While the VARK model focuses on how people prefer to learn, it does not necessarily mean that their preference match their abilities or strengths (Fleming and Baume 2006). Understanding that different preferences exist, however, does give teachers information about how to better assist their students, as they can create lessons that incorporate multiple styles. Video is generally considered a preference for the auditory learner. However, if graphs are incorporated, the visual learner should be more engaged. If this is also incorporated with a handout, those that prefer reading and writing can also benefit. By incorporating multiple styles, the multi-modal learner can also be assisted.

Video has become widely accepted as a teaching tool. Videos can make learning easier and teaching more consistent (Rasul et al 2007). As technology becomes more widely available, it is possible to reach broader audiences with video teaching tools. Disseminating information through video allows people from all over the world to gain access to the producer's message.

The Project:

An online search was conducted to find currently available video lessons about OA using Google. The search resulted in the discovery of many good resources that are currently available for people interested in this subject, including several videos. These videos include

The Acid Test by the Natural Resources Defense Council, Acidifying Waters Corrode Northwest Shellfish by the Public Broadcast System, Ocean Acidification by the North Carolina Aquarium, Ocean Acidification: Connecting science, industry, policy and public by the Plymouth Marine Lab, Sea Change: The Pacific's Perilous Turn by the Seattle Times, Ocean Acidification: Herbie the Hermit Crab by the Great Barrier Reef Marine Park Authority, Ocean Acidification by the Alliance for Climate Education, and The Other CO_2 Problem by the Ridgeway School in Plymouth, England (see Videos section page 23) .

While these videos were all excellent, there was no video that appeared to be designed as a classroom teaching tool to be used in middle schools. Many of these videos were not designed with children as the target audience, and the videos that were designed for children tended to be short, meaning 2 to 9 minutes, and not very comprehensive. Not a single video used an interview between an actual 8th grade student and a scientist. None of the videos found online were accompanied by a survey ("quiz").

I chose to create a documentary-style video with survey ("quiz") in order to cater to the visual, auditory, reading/writing, and multi-modal learning styles. As the intent of this project is to use my video in conjunction with hands-on - or kinesthetic – exercises, this should convey information to children in all of the different learning styles in order to maximize the effectiveness of teaching.

I worked with my advisor, Dr. Andreas Andersson, and San Diego, California, 8th grade student, Sammie Lurie, to create an interview that would answer several questions that kids want to know about OA. I felt that having a middle school child interviewing a scientist would keep the information accurate, accessible, and age-appropriate for children.

I compiled a video library of marine organisms donated by Hawaii videographers James Begeman and Jose Silva and scientists Dr. Richard Norris and Dr. Mario Lebrato of the Scripps Institution of Oceanography.

Several versions of the video were created. The videos were shown to my committee, my family, my friends, and their children to assess the best version. A final draft of the video was completed and approved by my advisor, Dr. Andreas Andersson in May of 2014.

I contacted several schools to solicit participation in my study of the video's effectiveness. Teachers with 6th, 7th, and 8th grade students in both Hawaii and California chose to participate in the study. Instructions for use were sent to Hawaii. The same procedure was followed in California. The survey was given first, the video was shown, then the survey was given a second time. Classroom testing occurred in May and June of 2014.

Methods:

A twenty-one minute documentary was created in Apple's iMovie. The script (see Appendix A) was written and edited over a period of three months. The script was tested in both Flesch Reading Ease and Flesch-Kinkaid Grade Level, which are measures of textual difficulty available in programs such as Microsoft Word, to ensure that the language was appropriate for middle school children. The script received a Flesch Reading Ease score of 69.4, which indicates that 69.4% of all readers could understand the document; a score of 65 or higher indicates plain English with short sentences and words with mostly two or less syllables (Flesch 1948). The script received a Flesch-Kinkaid Grade Level score of 6.5, which indicates people in grades 6.5 and higher should be able to understand the document (Kinkaid et al 1975). Approval of the script was received from Dr. Andreas Andersson in April 2014.

Audio was recorded using equipment from the UCSD Media Lab. Wireless lavaliers were utilized by both interview subjects, Sammie Lurie, an 8th grade student from San Diego, California, and Dr. Andreas Andersson from the Scripps Institution of Oceanography and sound was captured in a Marantz audio recording device. I used an Omni microphone for the voice overs and recorded into the Marantz audio recording device. Sound was enhanced in Adobe Audition. Music was provided royalty-free from Free Stock Music at http://www.freestockmusic.com.

Video was generously donated from several sources including James Begeman of the Kona Aggressor, Jose Silva of 5-Star Scuba, Dr. Richard Norris of the Scripps Institution of Oceanography, Ashleigh Palinkas of the Scripps Institution of Oceanography, Chris Neighbors of the Scripps Institution of Oceanography, and Dr. Mario Lebrato of the Scripps Institution of Oceanography. Additional filming was completed by Amy Bowman on the Center for Marine Biodiversity and Conservation's Canon Rebel DSLR. Other footage was downloaded from Stock Footage for Free at http://www.stockfootageforfree.com.

Motion graphics were created by Amy Bowman and Yatlong Sam Poon in Adobe After Effects on the Center for Marine Biodiversity and Conservation's media lab computer. Initial images were created on the same computer in Adobe Photo Shop.

An interview was conducted between local middle school student, Sammie Lurie, and Dr. Andreas Andersson of the Scripps Institution of Oceanography; the interview was filmed by Amy Bowman. Audio was recorded on two Wireless Lavalier microphones and run through a Marantz audio recorder.

Still images were provided by the Lurie Family, Dr. Andreas Andersson, Amy Bowman, the

NOAA website, and Flikr Creative Commons.

A fifteen question survey ("quiz") was created (see Appendix B) to be used in conjunction with the video lesson. The survey was reviewed by my committee prior to its use in a classroom setting. The survey has a dual purpose. It was designed first to assess baseline knowledge and second to determine how much was learned from watching the video. A ranking question was also included to test self-reporting of students' knowledge about the subject of ocean acidification both before and after watching the video.

The survey was given to 235 middle school children from Haley Van Noord's 7th grade class at Lahaina Middle School in Lahaina, Hawaii, Dan Grendziak's five 8th grade classes at Wangenheim Middle School in San Diego, California, and Andrea Morton's two 6th grade classes at High Tech Middle School in Chula Vista, California. The survey was given before watching the video to test baseline knowledge. The teacher collected the survey and did not give the children their scores. The children then watched the video lesson. The same survey was given a second time immediately after watching the video to test the differences in the answers, and assess if any changes occurred.

The results from the 235 students were input into Microsoft Excel and averaged to see the difference between the initial scores and the scores after watching the video. The scores were averaged for both pre- and post-video viewing. The self-reported knowledge data was also input and analyzed in Microsoft Excel and put into a ranking bar graph to see self-reported knowledge both before and after watching the video.

Results:

Prior to watching the video, the 235 children's self-reported knowledge about OA was mostly A. I have never heard of this term, B. I have heard this term but don't know what it means, or C. I know a little bit about OA. The majority of answers were choice A with 101 respondents. After the quiz, the children's self-reported knowledge changed to C. I have heard the term and know a little bit about it, D. I have heard the term and know a lot about it, or E. I know a lot about this term and can explain it to others. The majority of the answers were choice C with 90 respondents, closely followed by D with 84 respondents (See *Fig. 10*)

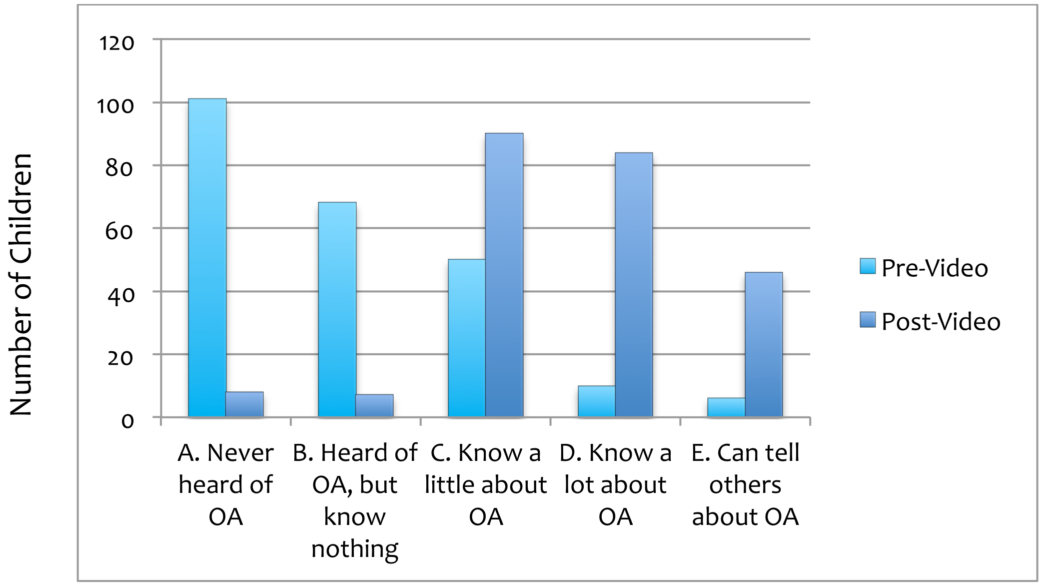

Fig. 10. Results showing the self-reported knowledge of the 235 children participating in the study. The X-axis shows the different answers. The Y-axis shows the number of children with that answer. Pre-video viewing scores are in turquoise.

The children's survey ("quiz") scores showed dramatic improvement as well. Before watching the video, the average score was 66.7%. After watching the video, the average score was 88%. That is a 21.3% increase after watching the video (See *Fig. 11*).

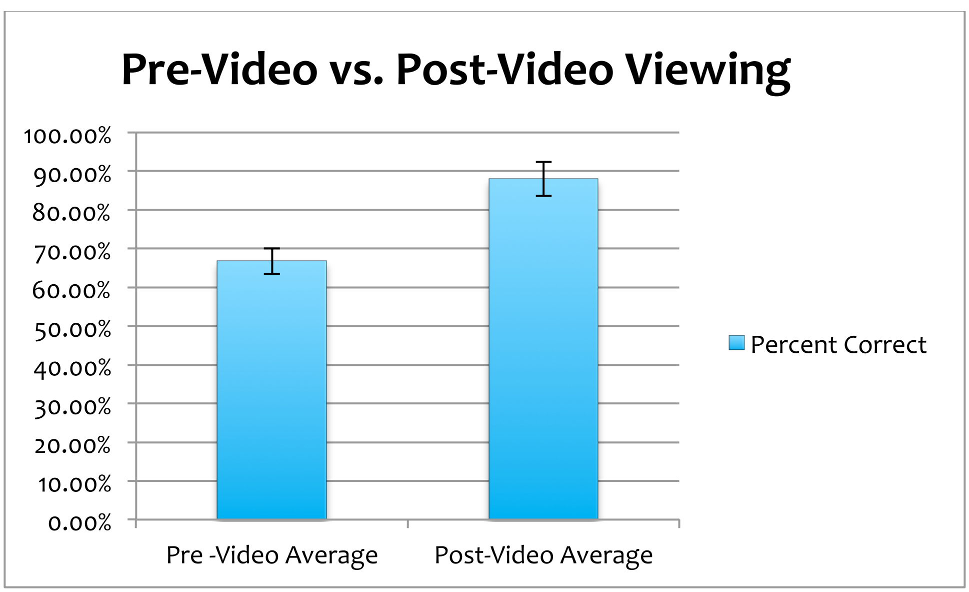

Fig. 11. Results showing the pre- and post-video survey score percentages of the 235 children participating in the study. This graph shows the pre-video scores to average at 66.7% while post-video scores average at 88%.

Not only did the children's scores improve between the two surveys, their self-confidence in their knowledge also increased. This indicates that the video was an effective tool for teaching the children some basic facts about OA and met the goal of my objective.

Discussion/Conclusion:

The straightforward solution to OA is the reduction of atmospheric CO_2 emissions and subsequent uptake by the ocean; if there is CO_2 in the atmosphere, there will be less CO_2 in the ocean. If we look at OA combined in the real world with other problems, such as atmospheric temperature increases and pollution, we can see that that additional anthropogenic stress will be placed on our planet's natural cycles.

To date, policies to reduce CO_2 emissions have been unsuccessful for a variety of reasons. The most effective strategy to reduce OA is to mitigate CO_2 emissions. The better-prepared humans are to face any upcoming changes in OA, the more successfully we will manage those changes. As policies have been unsuccessful, emphasis should be placed on education to encourage people to take actions to reduce CO_2 emissions. As studies have shown that children are more willing to take action on climate change issues than adults, it is important to get conservation messages to children early in life. This could lead to conservation-focused behavioral habits becoming ingrained before children purchase their first car.

This video project has shown that children were able to successfully score 21.3% higher on an OA survey ("quiz") after watching the video. Question 2 asked the children which gas caused OA. In the pre-test, only 39% were able to correctly identify that CO_2 caused OA. Post-test, every child was able to identify the correct gas.

While video was shown to be effective overall, scores could improve even more by addressing the one learning style that video does not address, the kinesthetic style. If this video were used in conjunction with the hands-on lesson plans like those developed in 2013 by Emily Gottlieb (Gottlieb 2013), it is likely that children would learn even more.

The video has been given to several schools and conservation groups already. It will become more widely available, as it will be made public after the Capstone Symposium on June 5, 2014. This will increase the access to information about OA for middle school children around the country. Moving forward, I would like to contact people in the international community to give away the video and quiz.

At the beginning of the year, my initial Capstone Proposal was to create a complete online lesson including video games with a learning platform called Versal. There were challenges, as time was a limiting factor. Going forward, creation of the video games to go with the video and the quiz will be implemented and the lesson link will be given away to schools and conservation groups. Providing free climate change education to younger people and learning facilitators, such as teachers and parents, should assist in reducing global CO_2 emissions.

New challenges will be faced if CO_2 emissions continue to rise. While reducing emissions may be difficult, as people do not want to change their habits and emerging nations would like to have a similar quality of life to developed nations, it would mean a reduction in OA that would ultimately benefit humankind. As children are more open to lifestyle changes than adults, starting to educate children at a younger age about climate change issues is likely to make a positive impact on this global problem. The benefit of using education to reduce CO_2 emissions and mitigate OA is that there are no negative environmental impacts.

References

Allen, Richard. (2011). Chemistry 151. Lecture from Fall Semester 2011 at UHMC in Kahului, Hawaii.

Barret, Scott. "On the theory and diplomacy of environmental treaty-making." *Environmental and Resource Economics* 11.3-4 (1998): 317-333.

Barry, J. (2013). The Sustainability of Ocean Resources. In Practicing Sustainability (pp. 201-205). Springer New York. Web Accessed March 18, 2014 http://link.springer.com/chapter/10.1007/978-1-4614-4349-0_39#page-1

Caldeira, K., & Wickett, M. E. (2003). Oceanography: anthropogenic carbon and ocean pH. *Nature*, *425*(6956), 365-365. Web accessed March 19, 2014. http://www.nature.com/nature/journal/v425/n6956/abs/425365a.html

Canadell, J. G., Le Quéré, C., Raupach, M. R., Field, C. B., Buitenhuis, E. T., Ciais, P., ... & Marland, G. (2007). Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks. Proceedings of the national academy of sciences, 104(47), 18866-18870. Web accessed March 18, 2014. http://www.pnas.org/content/104/47/18866.short

Carlton, D. W., & Perloff, J. M. (2000). Modem industrial organization. *Reading*. Web Accessed March 18, 2014. http://wps.aw.com/aw_carltonper_modernio_4/21/5566/1424929.cw/index.html

Cesar, H.J.S., Burke, L., and Pet-Soede, L. (2003). The Economics of Worldwide Coral Reef Degradation. Cesar Environmental Economics Consulting, Arnhem, and WWF-Netherlands, Zeist, The Netherlands. 23 pp. Web accessed December 7, 2013. http://coralreef.noaa.gov/redirect.html?newURL=http://assets.panda.org/downloads/cesardegradationreport100203.pdf

Cordero, E., Todd, Anne Marie, and Abellerra, D. (2008). Climate Change Education and the Ecological Footprint. *Bulletin of American Meterological Society*.865:872. Doi: 10.1175/2007BAMS2432.1. Web Accessed May 15, 2014. http://scholarworks.sjsu.edu/comm_pub/2/

Crampton, Eric. (2012). Good graphs are general, or how a carbon tax is like drug legalization. Offsetting Behaviour. Blog. Web accessed December 7, 2013. http://offsettingbehaviour.blogspot.com/2012/10/good-graphs-are-general-or-how-carbon.html

Dyck, A.J. and U.R. Sumaila. (2010). Economic impact of ocean fish populations in the global fishery. Journal of Bioeconomics. Web accessed March 18, 2014. http://download.springer.com/static/pdf/243/art%253A10.1007%252Fs10818-010-9088-3.pdf?auth66=1386627047_50743ffcc9a7d1796b8e7aff31733d31&ext=.pdf

Environmental Protection Agency - EPA. (2013). Overview of Greenhouse Gases. *EPA Website*. Web accessed December 10, 2013. http://www.epa.gov/climatechange/ghgemissions/gases/co2.html

Farley, K. A., & Eltgroth, S. F. (2003). An alternative age model for the Paleocene–Eocene thermal maximum using extraterrestrial ^{3}He. *Earth and Planetary Science Letters*, *208*(3), 135-148. Web accessed June 10, 2014. http://www.sciencedirect.com/science/article/pii/S0012821X03000177

Fleming, N., and Baume, D. (2006) *Learning Styles Again: VARKing up the right tree!*, Educational Developments, SEDA Ltd, Issue 7.4, Nov. 2006, p4-7. Web accessed May 15, 2014. http://www.vark-learn.com/documents/educational%20developments.pdf

Fleming, N. D. (2001). *Teaching and learning styles: VARK strategies*. Christchurch, New Zealand: N.D. Fleming. ISBN 0-473-07956-9.

Fleming, N. D. (2014) "VARK". Web accessed June 10, 2014. http://www.mybrcc.edu/vark/

Flesch, R. (1948). A new readability yardstick. *Journal of applied psychology*, *32*(3), 221. Web accessed June 10, 2014. http://psycnet.apa.org/journals/apl/32/3/221/

Gattuso, J. P., & Hansson, L. (Eds.). (2011). *Ocean acidification*. Oxford University Press.

Gattuso, J. P., Mach, K. J., & Morgan, G. (2013). Ocean acidification and its impacts: an expert survey. Climatic Change, 1-14. Web accessed December 4, 2013. http://link.springer.com/article/10.1007/s10584-012-0591-5#page-1

Gibbons, R. S. (1997). An introduction to applicable game theory. *The Journal of Economic Perspectives*, Vol. 11, No. 1.

Gottlieb, Emily. (2013). The changing Climate of Science Education: Bringing Ocean Acidification to Middle School Teachers. MAS MBC Capstone Report, Scripps Institution of Oceanography. Web accessed June 10, 2014. http://anderssonoceanresearch.com/documents/OA_explorations.pdf

Hawk, Thomas F., and Shah, Amit J. (2007) Using Learning style Instruments to Enhance Student Learning. *Decision Sciences Journal of Innovative Education, 5(1).* Web accessed May 15, 2014. http://ftp.paulchrisluke.com/310/p3/Using%20Learning%20Style%20Instruments.pdf

Hönisch, B., Ridgwell, A., Schmidt, D. N., Thomas, E., Gibbs, S. J., Sluijs, A., ... & Williams, B. (2012). The geological record of ocean acidification. *Science*, *335*(6072), 1058-1063

Intergovernmental Panel on Climate Change – IPCC. (2007). IPCC 4th Assessment Report: Climate Change 2007. Web accessed March 19, 2014. https://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-projections-of.html

Jacobsen, Mark. (2013). Economics 281. Lecture conducted on October 15 and 22, 2013 at UCSD in San Diego, California.

Keohane, Nathaniel O. and Olmstead, Sheila M. (2007). Markets and the Environment. Island Press.

Kincaid, J. P., Fishburne Jr, R. P., Rogers, R. L., & Chissom, B. S. (1975). *Derivation of new readability formulas (automated readability index, fog count and flesch reading ease formula) for navy enlisted personnel* (No. RBR-8-75). NAVAL TECHNICAL TRAINING COMMAND MILLINGTON TN RESEARCH BRANCH. Web accessed June 10, 2014. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA006655

Kirby, Alex. (2013). Least developed countries agree to cut greenhouse gas emissions. Climate News Network, part of Guardian Environment Network. Web accessed December 8, 2013. http://www.theguardian.com/environment/2013/apr/03/climate-change-greenhouse-gas-emissions

Krukowska, Ewa. (2013). Black Treasure in Poland Clouds UN Warming Negotiations. Bloomberg. Web Accessed December 8, 2013. http://www.bloomberg.com/news/2013-11-13/black-treasure-in-poland-clouds-un-warming-negotiations.html

Lenzen, Manfred, and Murray, Joy. (2001). The Role of Equity and Lifestyles in Education about Climate Change: Experiences from a Large-Scale Teacher Development Program. *Canadian Journal of Environmental Education, 6.* Web accessed May 15, 2014. http://files.eric.ed.gov/fulltext/EJ661761.pdf

Le Quéré, C., Raupach, M. R., Canadell, J. G., Marland, G., Bopp, L., Ciais, P., ... & Woodward, F. I. (2009). Trends in the sources and sinks of carbon dioxide. *Nature Geoscience*, *2*(12), 831-836. Web accessed March 19, 2014. http://www.nature.com/ngeo/journal/v2/n12/abs/ngeo689.html

Méhay, S., Keller, C. E., Bernasconi, S. M., Weissert, H., Erba, E., Bottini, C., & Hochuli, P. A. (2009). A volcanic CO2 pulse triggered the Cretaceous Oceanic Anoxic Event 1a and a biocalcification crisis. *Geology*, *37*(9), 819-822. Web accessed March 17, 2014. http://geology.gsapubs.org/content/37/9/819.short

National Oceanic and Atmospheric Administration - NOAA. (no date) "Ocean Acidification". Web accessed June 6, 2014. http://www.pmel.noaa.gov/co2/story/Ocean+Acidification

National Oceanic and Atmospheric Administration - NOAA. (2013). The oceans are the trading routes for the planet. Web accessed December 6, 2013. http://oceanservice.noaa.gov/facts/oceaneconomy.html

National Research Council - NRC. (2010). Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean. National Academies Press, Washington. Web accessed December 3, 2013. http://www.nap.edu/openbook.php?record_id=12904

Norris, R.D., Turner, S.K., Hull, P.M., Ridgwell, A. (2013). Marine Ecosystem Responses to Cenozoic Global Change. *Science.* Vol. 341 no. 6145 pp. 492-498. Web accessed March 17, 2014. http://www.sciencemag.org/content/341/6145/492

Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., ... & Yool, A. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature*, *437*(7059), 681-686. Web accessed March 18, 2014. http://www.nature.com/nature/journal/v437/n7059/abs/nature04095.html

Pizer, W. A. (2002). Combining price and quantity controls to mitigate global climate change. *Journal of public economics*, *85*(3), 409-434. Web accessed March 18, 2014. http://www.sciencedirect.com/science/article/pii/S0047272701001189

Rasul, Saima, Qadir Bukhsh, and Shazia Batool. "A study to analyze the effectiveness of audio visual aids in teaching learning process at uvniversity level." *Procedia-Social and Behavioral Sciences* 28 (2011): 78-81. Web accessed May 15, 2014. http://www.sciencedirect.com/science/article/pii/S1877042811024554

Raven, John, K. Caldeira, H. Elderfield, O. Hoegh-Guldberg, P. Liss, Ulf Riebesell, J. Shepherd, C. Turley, and A. Watson. (2005). Ocean acidification due to increasing atmospheric carbon dioxide. The Royal Society. Web accessed March 18, 2014. http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2005/9634.pdf

Ries, Justin. (2011). Skeletal Mineralogy in a high CO_2 World. *Journal of Experimental Marine Biology and Ecology.* Volume 403, Issues 1–2, Pages 54–64. Web accessed March 18, 2014. http://www.sciencedirect.com/science/article/pii/S002209811100164X

Rodolfo-Metalpa, R., Houlbrèque, F., Tambutté, É., Boisson, F., Baggini, C., Patti, F. P., ... & Hall-Spencer, J. M. (2011). Coral and mollusc resistance to ocean acidification adversely affected by warming. Nature Climate Change, 1(6), 308-312. Web accessed December 8, 2013. http://www.nature.com/nclimate/journal/v1/n6/full/nclimate1200.html

Royer, Dana. (2005). CO2-forced climate thresholds during the Phanerozoic. *Geochimica et Cosmochimica.* Acta 70 (2006) 5665–5675. Web accessed March 18, 2014. http://droyer.web.wesleyan.edu/PhanCO2(GCA).pdf

Siegenthaler U, Stocker TF, Monnin E, Luthi D, Schwander J, Stauffer B, Raynaud D, Barnola JM, Fischer H, Masson-Delmotte V, Jouzel J (2005) Stable carbon cycle-climate relationship during the late Pleistocene. *Science* 310:1313–1317 Web accessed December 10, 2013. http://www.sciencemag.org/content/310/5752/1313

Smith, Shane. (2003). Game Theory. Beyond Intractability. Editors Guy Burgess and Heidi Burgess. Conflict Research Consortium, University of Colorado, Boulder, Colorado, USA. Web Accessed December 7, 2013. http://www.beyondintractability.org/essay/prisoners-dilemma

The Ocean Project (2009). America, the Ocean, and Climate Change: New Research Insights for Conservation, Awareness, and Action Key Findings. Web Accessed May 15, 2014. http://theoceanproject.org/wp-content/uploads/2011/12/America_the_Ocean_and_Climate_Change_KeyFindings_1Jun09final.pdf

University of Michigan. (2006). World Fisheries: Declines, Potential and Human Reliance. Web Accessed March 18, 2014. http://www.globalchange.umich.edu/globalchange2/current/lectures/fisheries/fisheries.html

Waldbusser, G. G., Brunner, E. L., Haley, B. A., Hales, B., Langdon, C. J., & Prahl, F. G. (2013). A developmental and energetic basis linking larval oyster shell formation to acidification sensitivity. Geophysical Research Letters, 1-6. Web accessed December 8, 2013. http://onlinelibrary.wiley.com/doi/10.1002/grl.50449/full

Williamson, P., & Turley, C. (2012). Ocean acidification in a geoengineering context. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *370*(1974), 4317-4342. Web accessed March 10, 2014. http://rsta.royalsocietypublishing.org/content/370/1974/4317.full.pdf+html

Worsley, Anthony, and Grace Skrzypiec. "Environmental attitudes of senior secondary school students in South Australia." *Global Environmental Change* 8.3 (1998): 209-225. Web Accessed May 15, 2014. http://www.sciencedirect.com/science/article/pii/S0959378098000168

Zeebe, R. E., Zachos, J. C., Caldeira, K., & Tyrrell, T. (2008). Carbon emissions and acidification. *SCIENCE-NEW YORK THEN WASHINGTON-*, *321*(5885), 51.

Existing Videos

"The Acid Test" by the Natural Resources Defense Council.
http://www.youtube.com/watch?v=5cqCvcX7buo

"Acidifying Waters Corrode Northwest Shellfish" by the Public Broadcast System.
http://www.youtube.com/watch?v=x7MpI9dZIjk

"Ocean Acidification" by the North Carolina Aquarium.
http://www.youtube.com/watch?v=kxPwbhFeZSw

"Ocean Acidification: Connecting science, industry, policy and public" by the Plymouth Marine Lab. http://www.youtube.com/watch?v=_BPS8ctVW2s

"Sea Change: The Pacific's Perilous Turn" by the Seattle Times. http://bcove.me/xupis5jw

"Ocean Acidification: Herbie the Hermit Crab" by the Great Barrier Reef Marine Park. Authority. http://www.youtube.com/watch?v=RnqJMInH5yM

"Ocean Acidification" by the Alliance for Climate Education.
http://www.youtube.com/watch?v=Wo-bHt1bOsw

"The Other CO_2 Problem" by the Ridgeway School in Plymouth, England.
http://www.youtube.com/watch?v=kvUsSMa0nQU

Appendix A

Amy Bowman
Losing Base: Education and Changing Ocean Chemistry Narrative
Feb. 11, 2014

The ocean hides countless treasures. It is full of amazing creatures. Many are still waiting to be discovered. Some people say that we know more about the surface of the moon than we do about the seafloor of the ocean. Even though we have explored space for many years, we have not yet found another planet with a liquid ocean exactly like ours. The ocean sustains life on Earth. It is one thing that makes our planet unique.

Underwater scene with multiple creatures

From the smallest bacteria to the largest whales, we find beautiful and enchanting life forms in the ocean. Many seem to come from science fiction movies; they don't look real. Somehow they live and thrive here on planet Earth. Every time we explore the deep ocean, we find new and fascinating creatures. The ocean is a world of wonder.

Various stills, bacterium and blue whale. Squid mating dance

Meet Sammie Lurie, an 8th grader from San Diego, California. He loves the ocean and is an avid boogie boarder. He spends a lot of time at the ocean with his friends and family. Sammie also loves seafood. He has learned that life on this planet wouldn't exist without the ocean. Because of this, Sammie is very concerned about the future, especially since hearing about ocean acidification. He wanted to find out more about this subject, and went to the Scripps Institution of Oceanography to talk with Dr. Andreas Andersson, a scientist and expert in the field of ocean acidification.

Scientists use a tool called the pH scale to measure acids and bases in liquids. The scale goes from 0 to 14. Numbers under 7 are acids. Common acids in the house include vinegar, orange juice, and soft drinks. Numbers above 7 are bases. Common bases in the house include olive oil, baking soda, and bleach. A liquid like pure water can be neutral with a pH of 7, right in the middle. Because of the extra carbon dioxide people put into the atmosphere from burning fossil fuels, the pH of the ocean is going down; this means it is becoming more acidic. Since ocean water is actually a base, you could also say it is becoming less basic.

pH cartoon.

The ocean is important to the plants and animals that live there and it is important to people too. It provides food for our tables and jobs for our families. Almost a quarter of all of our protein comes from ocean animals such as fish, lobster,

Seafood at the market, fishing boat, scuba boat. Recreational activities, Sailing.

Cartoon car and power plant smokestack.

Cartoon of plant showing CO_2 in and O_2 out

and clams. Many people work in the fishing and ocean tourism industries. People around the world who live near the ocean also go there for fun.

Before airplanes, people travelled long distances across the ocean; many still do.

The ocean is also important to science. Many researchers study the sea and make important discoveries. Scientists discovered that all of the algae growing in our ocean make almost half of the oxygen in the air we breathe. Not only do scientists learn about plants and animals and the ecosystem, they also create new medicines from the mysterious creatures beneath the sea.

Scientists by a microscope. Diatom still. Macro alga still. Medicine.

The ocean does something else very important: it controls our climate. Wind blows across the ocean, which creates waves and drives the surface currents. Water evaporates from the ocean and returns in the form of rain. The ocean keeps our planet’s temperature more stable. Without the ocean, life on this planet might not even exist.

Clouds blowing over the ocean. Rainstorm on the ocean. Waves.

We know that the things people do affect the ocean. Pollution has become a problem. There are many forms of man-made pollution in the ocean including chemicals, sewage, and plastic. And there is another type of pollution; one that is harder to see with our eyes and it affects both the ocean and the atmosphere.

Agricultural spraying, sewage pipe, plastic in the ocean.

The atmosphere is a layer of different gases that surround and protect Earth like a blanket. The gases in the atmosphere have been balanced for many years, but people are changing that balance.

Cartoon of the atmosphere.

People burn gasoline in cars and burn oil and coal in electric power plants. When people burn these fossil fuels, they add extra man-made carbon dioxide gas to the atmosphere. Carbon dioxide is chemical that also occurs naturally and is necessary for plants. Plants use sunlight and carbon dioxide to make food and grow. Plants take in carbon dioxide and let out oxygen. Plants need carbon dioxide to survive. So if it is natural and necessary, why are we worried about carbon dioxide? Too much carbon dioxide causes a problem called ocean acidification. Natural and man-made carbon dioxide combine in the atmosphere and mix with ocean water to cause a chemical reaction that makes ocean water more acidic; this removes the building blocks some animals need to create their shells. Since there are now over 7 billion people on the planet, people are creating more carbon dioxide than ever before, and carbon dioxide causes Ocean Acidification.

Cartoon CO_2 molecule mixing with H_2O. Cartoon seashells with bubble thought “no building blocks”

For a long time, people weren't sure where all of the extra carbon dioxide from burning fossil fuels was going. The ocean has been saving us from too much carbon dioxide in our atmosphere by absorbing approximately 30% of it.

Ocean waves with title 30%

Before people started driving cars and burning huge amounts of coal and oil for electricity, putting extra carbon dioxide in the atmosphere, the pH of the ocean was approximately 8.2. In the last 200 years, it has dropped to 8.1. While this may not sound like much, a 0.1 difference on the pH scale is nearly a 30% change in the ocean's acidity.

8.2 arrow down to 8.1. Then cartoon of 0.1 =30% change

Too much carbon dioxide is bad for some of the animals that live in the ocean. Animals that create reefs and shells, like corals and clams, can have problems. When the water becomes more acidic the building blocks these animals need to create reefs and shells are removed. Many plants and animals will be affected by ocean acidification. If the water becomes too acidic, they might not survive. Without these plants and animals, it would be difficult for us to live as comfortably as we do now.

Show coral and shellfish malformed asking where are my building blocks? Cartoon dissolving shell

Coral reefs are the jewels of the ocean; they are full of hidden treasures. Reefs grow in tropical places where the water is warm and clear. For the animals that live there, life is a delicate balance. Without the tiny coral animals, the tropics would be like deserts of the ocean. Corals build huge structures. These provide food and shelter to many other animals. Corals help other animals survive. And corals are threatened by ocean acidification. Many animals live on the coral reefs, and they, too could be affected by ocean acidification if corals do not survive.

Coral reef footage.

While this sounds scary, there are things we can do to help. One of the best things we can do is to use less electricity and gasoline. At home, if you aren't using something like the computer or the light, turn it off. We can also drive less: we can walk more, ride bicycles, or use public transportation. Instead of putting waste into landfills, reducing, reusing, and recycling also lowers carbon dioxide emissions.

Conservation oriented images

There are many other things that we can do to help the planet and the ocean. Tell others what you know about the problem with carbon dioxide. By working together, we can solve this problem.

Working together

Appendix B

Amy Bowman
Losing Base: Education and Changing Ocean Chemistry Survey "quiz"

Losing Base: Changing the Ocean Quiz

Name: ____________________________

Date: _____________________________

Ocean acidification

a. I have never heard the term.
b. I have heard the term but don't know what it is.
c. I have heard the term and know a little bit about it.
d. I have heard the term and know a lot about it.
e. I know a lot about this term and can explain it to others.

1. On the pH scale, is ocean water acidic?

a. Yes, it is acidic.
b. No, it is basic.
c. No, it is neutral

2. Which gas causes ocean acidification?

a. Oxygen
b. Nitrogen
c. Carbon dioxide
d. Carbon monoxide

3. What can happen to some animals because of ocean acidification?

a. It can be more difficult for some animals to make shells.
b. It can be easier for all animals to build shells.
c. It will make no difference to any animal.

4. As more carbon dioxide is released into the atmosphere,

a. ocean water will become more acidic.
b. ocean water will become less acidic.
c. Nothing.

5. How much carbon dioxide is absorbed by the ocean?

a. About half.
b. None.
c. Almost all.
d. About one third.

6. Coral reefs provide ____________________ to other marine organisms.

a. food
b. shelter
c. all of the above
d. none of the above

7. If coral reefs are lost, other animals:

a. may be negatively impacted.
b. may be positively impacted.
c. will experience no changes.

8. Types of pollution in the ocean include plastic, chemicals, sewage and CO2:

a. true
b. false

9. We can reduce human-created sources of carbon dioxide by:

   a. driving less.
   b. using less electricity.
   c. reducing, reusing, and recycling.
   d. all of the above.

10. Ocean acidification happens when:

   a. people pour acid into the ocean.
   b. the chemistry of the ocean changes to become more acidic.
   c. fish swim faster to make ocean water more acidic.
   d. animals eat so much that they make the ocean more acidic.

11. The ocean:

   a. controls the climate.
   b. provides both food and jobs to people.
   c. is home to plants that create oxygen.
   d. all of the above.

12. The atmosphere is:

   a. a layer of different gases that surround and protect the planet.
   b. a layer of water that surrounds and protects the planet.
   c. clouds.

13. On the pH scale:

   a. numbers above 7 are acids.
   b. numbers above 7 are bases.
   c. numbers above 7 are neutral.
   d. none of the above.

14. The pH of the ocean was ______ but has changed to _____. On the pH scale this is a _____ change.

   a. 8.2 8.1 30%
   b. 10 5.1 50%
   c. 2.2 6.2 100%

15. Ocean acidification is a problem that:

   a. we can help by burning less fossil fuels.
   b. we can help by holding our breath.
   c. we can't do anything about.
   d. all of the above.
   e. none of the above.

Appendix C

Survey Results

Child	Pre-Video Sc	Post-Video S	Pre-Video Se	Post-Video Self-Reported Knowledge
Aaron	6	9	3	1
Adrian	10	11	5	4
Alleona	9	12	2	3
Anthony	7	15	1	1
Brett	11	15	2	4
Brittnie	12	13	1	3
Cedric	10	14	1	4
Charlene	10	13	2	3
Cindy	11	12	1	3
Danielele	12	14	3	4
Glen	10	14	3	4
Hailey	11	15	2	5
Hana L	10	15	1	5
Hana T	7	15	1	3
Isaac	6	14	2	1
Jaymee	11	15	2	5
Jihad	4	14	2	4
Jorge	12	14	2	4
Khanh	12	15	2	3
Leon	13	14	1	4
Llana	13	15	2	5
Mario	11	15	1	4
Nick	10	14	3	4
Regina	15	14	2	4
Sariah	9	14	2	4
Sebastian	9	15	1	3
Shelby	7	15	3	5
Sierra	13	14	1	4
Thomas	14	15	3	4
Tijana	11	14	2	5
Tommy	9	14	1	3
Tygar	8	13	1	3
Tyson	11	14	3	4
Xavier	9	12	1	3
Zachary	5	15	1	4
Abdi	10	13	1	3
Alexandra	10	11	1	3
Alysha	8	12	1	4
Amanda	9	12	2	4
Andrew	5	9	3	3
Billy	9	13	1	5
Cecille	9	15	1	3

Christine	12	15	2	4
Ciara	13	14	1	4
Diana	10	14	1	3
Erek	11	15	2	4
Gelador	12	14	1	5
Isaiah	11	14	1	5
Jasmine	6	5	1	3
Jesse	8	13	1	4
Jestonie	8	11	1	3
Jordyn	13	14	1	5
Jose	6	13	2	1
Joseph	11	14	3	4
Joshua	10	15	3	3
Juaquin	11	14	2	4
Justin	10	13	1	1
Lucas	11	15	3	5
Lynn	12	13	1	3
Lynne	10	13	1	3
Melisa	11	14	2	4
Michayla	4	8	1	3
Naethan	10	13	1	3
Ramyl	9	15	1	5
Samantha	12	12	1	5
Shane	11	15	1	5
Skylar	10	15	2	5
Steven	10	14	1	5
Worasate	3	7	1	5
Xikai	4	11	3	5
Adelei	13	14	2	3
Albert	12	15	3	3
Amy	12	15	3	4
Andrea	11	12	2	4
Andrew	14	14	2	4
Anthony G	8	12	3	4
Anthony P	12	14	2	4
Brandon	12	14	3	4
Dylan	13	14	1	4
Edward	11	14	2	4
Evans	12	15	2	5
Fiorelia	12	14	2	4
Janelle	11	15	3	3
Jessica	10	15	2	3
Jimmy	12	14	1	1

Jordyn	9	15	1	5
Kat	13	15	5	5
Keegan	7	9	3	4
Kenneth	13	15	2	3
Leia	12	14	1	4
Megan	14	15	2	4
Melody	5	13	1	3
Mordecai	11	13	2	3
Namkhue	11	14	1	4
Nathalia	13	11	2	2
Olivia	13	15	2	4
Oren	12	15	2	5
Sandy	6	12	2	4
Than	9	15	1	3
Tiffany	12	14	2	3
Tobey	13	15	1	5
Tony	13	14	1	3
Tori	14	15	3	5
Yves	11	14	3	4
Adrienne	11	13	3	4
Amber	14	15	2	5
Anneliese	13	15	3	3
Ares	14	15	2	5
Brenden	9	14	2	5
Brigitte	8	15	1	3
Carolyn	10	13	2	2
David	12	15	1	4
Davis	13	15	2	3
Emily	5	15	1	4
Erica	12	15	1	5
Gabriel	9	12	1	3
Hannah	14	15	1	1
Jaaden	10	15	2	4
Joanna	11	14	1	3
Jonathan	13	15	1	5
Joshua	8	15	1	3
Julianna	5	11	1	3
Justin	9	14	1	3
Keiranna	7	11	2	4
Kevin	14	14	1	4
Kiara	14	14	2	4
Liz	13	15	1	3
Mary Ann	11	14	1	3

Megan	12	13	2	3
My Huong	9	11	1	5
Natalie	13	15	1	4
Rem	11	15	3	3
Roland	13	15	1	3
Ryan	13	14	1	5
Shawn-Dale	11	14	1	4
William	13	15	1	5
Abagaile C	12	13	3	4
Rafael C	11	12	1	4
Taylor D	3	12	1	3
Josh E	9	13	2	4
Alan G	10	13	1	3
Eachen H	14	15	2	3
Edgar J	10	14	2	3
Rica J	11	13	1	3
Luis J	9	13	2	3
Kristina L	7	14	1	4
Mary Grace L	8	13	2	4
Serena L	11	15	2	3
Matthew M	13	14	2	4
Michaela M	13	15	2	3
Daniel N	11	14	1	3
Robert N	14	15	2	3
Alex P	6	15	1	3
Nikki P	11	15	1	3
Anna P	7	14	3	3
Ana R	13	14	2	3
Phummin R	10	15	2	2
Taya R	5	5	3	3
Brandon T	4	14	1	5
Cheyenne T	4	9	1	3
Christeen T	11	15	1	3
Kent T	7	13	3	3
Nick V	13	15	1	3
Bruce V	12	13	1	2
Nathaniel W	8	15	1	4
Aiden	12	14	4	5
Alex M.	8	10	3	3
Alex V.	10	11	3	4
Alexis	13	11	3	5
Alona	12	10	1	3
Ami	4	9	4	4

Andrew	10	14	4	4
Bryant	9	11	3	3
Cassandra	9	8	2	3
Drake	11	13	4	4
Ernesto	11	15	3	3
Elizabeth	13	14	3	4
Gavin	12	14	3	4
Guy	12	15	4	5
Heriberto	10	11	3	4
Ivanna	12	14	2	3
Jaddin	10	14	5	5
Lazaro	9	14	2	3
Lexi	10	13	3	4
Marissa	11	13	4	4
Mick	7	8	3	5
Nazaret	3	7	2	4
Robert	4	11	1	4
Shayne	12	14	3	4
Valeria	13	13	3	4
Alicia	11	14	3	3
Arlyn	9	11	1	3
Brandon	10	13	3	3
Claudia	7	8	3	4
Clayton	9	15	3	3
Dante	11	15	5	4
Deandre	10	11	2	5
Diego	12	14	4	4
Drake	12	14	3	2
Eli	12	15	3	5
Emma	11	14	3	3
Eric	8	9	4	2
Fernanda	10	14	2	3
Isabella	6	9	5	3
Josiah	5	9	1	1
Kelley	11	13	4	4
Max	11	14	3	4
Nantai	9	12	3	4
Savannah	7	13	2	5
Sami	12	14	5	3
Sydney	10	13	3	3
Tommy	6	8	4	3
Vanessa	8	8	1	5
Xander	10	14	3	3

Divina C	11	12	1	5
Kylan C	7	8	2	3
Chance D	8	12	1	4
Rylee-Ann D	8	15	1	5
Hae H	12	15	1	4
Hunter H	11	15	1	4
Lennox K	7	12	1	4
Gunnar L	11	15	1	4
Ricardo L	9	15	1	3
Janelle M	8	10	2	3
Maritza M	9	11	1	4
Isabella O	12	13	2	5
Lexa O	10	14	2	3
Shana R	11	14	1	5
Teani R	4	6	1	3
Blessing S	3	6	2	3
Isikeli T	9	14	1	2
Jacob T	7	10	1	3
Jett T	10	14	1	4
Santiago V	7	15	1	3
Sam W	9	12	1	3
	10.0042553	13.2	1.94468085	3.64680851