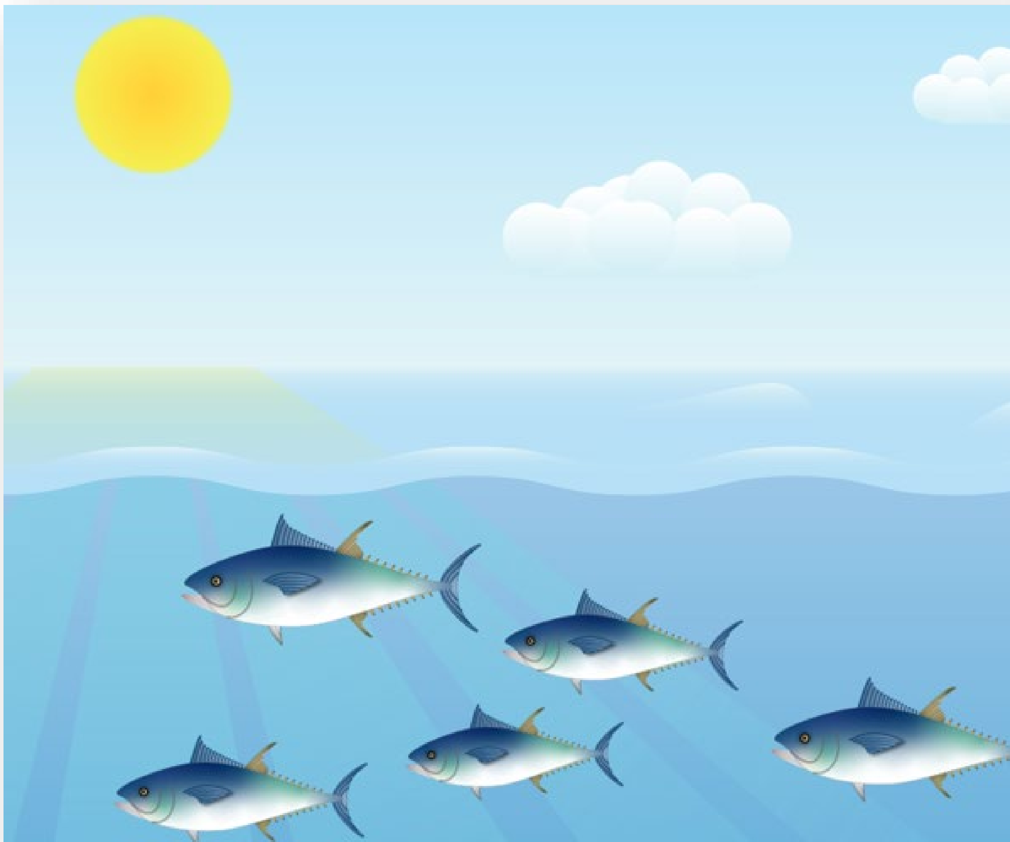
Teachers Guide for using *Ocean Protector* in the classroom



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Introduction

The amount of carbon dioxide (CO_2) in the atmosphere is increasing, due to the burning of fossil fuels and other human activities. How do these changes, as well as other human activities, affect the chemistry of the ocean?

The online program *Ocean Protector* is a game-based learning tool that teaches students about ocean acidification (OA), the effects on humans and marine life, and ways to help minimize the effects. This game-based curriculum integrates current OA data/models from NOAA and scientific literature into a framework of decisions and outcomes that align with Next Generation Science Standards. The program first guides students through learning the background about OA. Following this foundational lesion, students enter the scenario with a given role, such as a fishing boat captain, marine park ranger, scuba tour guide instructor, etc. Students are tasked with making decisions for how to reduce OA impacts on their character and marine life. Students will evaluate and select decisions based on the data provided and their own knowledge, and then they will analyze how their decision influenced OA impacts in real-time. This decision-driven experience helps students construct explanations, reason effectively, and become self-directed learners involving OA science and ocean literacy.

The document provides a background on OA, which is sourced from NOAA Ocean Data Education Project (2019). This background and introduction are followed by a structured lesson plan for using Ocean Protector, including sections for Objectives, Background, Materials, and Procedure. Complementary material is also listed, including sections that outline alignment with Next Generation Science Standards and an example of Module Integration.

Ocean Acidification Background

The Basics of Ocean and Coastal Acidification

Burning fossil fuels, and other human activities, releases CO_2 into Earth's atmosphere. This not only leads to a warmer Earth (i.e., global climate change, the greenhouse effect), but also changes the chemistry of Earth's oceans. The ocean is a "carbon sink," which means that it removes CO_2 from the atmosphere. The ocean currently absorbs approximately 26% of human-caused CO_2 emissions from the atmosphere. When CO_2 dissolves in seawater, a series of chemical reactions occur resulting in the increased concentration of hydrogen ions. This increase causes the seawater to become more acidic. Ocean acidification refers to a reduction in the pH of the ocean over an extended period of time, caused primarily by uptake of carbon dioxide (CO_2) from the atmosphere. Coastal acidification refers to the same processes resulting from the absorption of atmospheric CO_2, as well as several additional, local-level processes, including the excess input of nutrients from shore (from fertilizers, wastewater, animal manure and more). Coastal acidification generally exhibits more variability over shorter time scales relative to open ocean acidification. Acidification is affecting the entire world's oceans. As the pH of ocean water decreases, there is a resulting decrease in the amount of carbonate ions available for many marine organisms to form their calcium carbonate shells. Oysters, clams, corals, and other shell-building creatures are less able to precipitate the mineral aragonite, which they use to build or rebuild their skeletons. As marine life is impacted, so too are economies that are dependent on fish and shellfish for food.

Carbon Cycling

Carbon cycles naturally between the atmosphere, the land, and the ocean due to multiple processes, including photosynthesis and respiration. Since the industrial revolution, carbon dioxide levels in the atmosphere have increased by 30%. This increase is primarily the result of fossil fuel emissions and deforestation. Some of the excess, human-caused CO_2 is absorbed, like a sponge, by the ocean. As CO_2 dissolves into the ocean, a series of chemical reactions occur that result in the increased concentration of hydrogen ions and the reduction of pH. This process is called ocean acidification. From long-term ocean measurements and observations, we know that ocean surface waters have become 30% more acidic over the last 150 years as they have absorbed large amounts of CO_2 from the atmosphere.

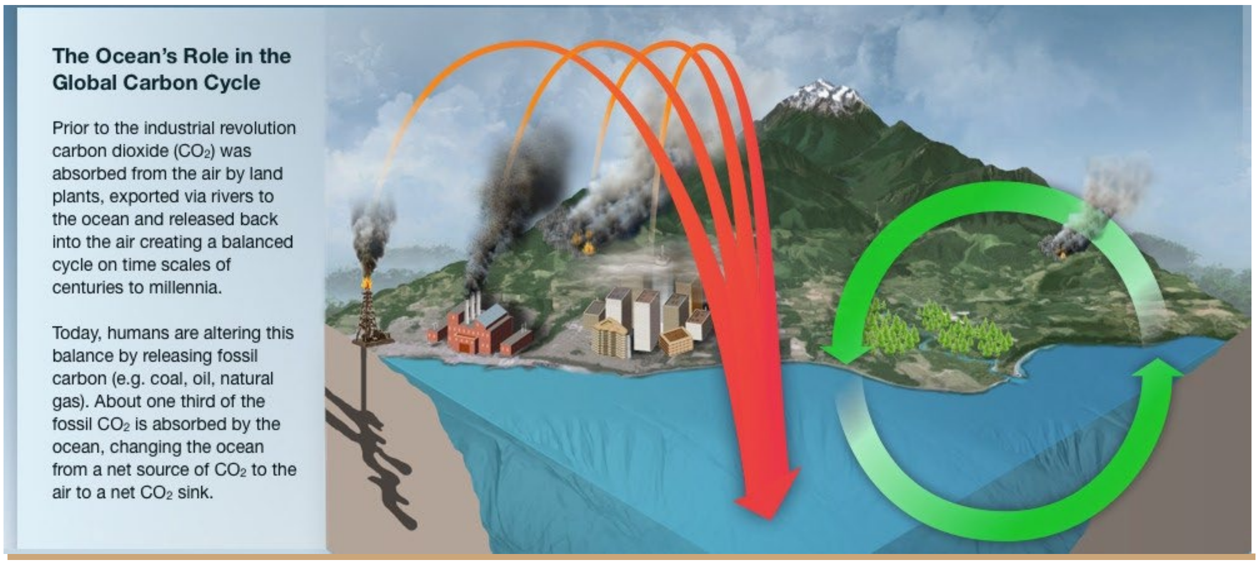

Image credit: Center for Environmental Visualization & NOAA PMEL Carbon Group

Review of pH

pH is the measure of the hydrogen ion concentration in a solution. pH is used to express acidity or alkalinity on a scale of 0 to 14. The pH of pure water is considered neutral and has a pH value of 7. Values above 7 are basic, or alkaline. Values below 7 are acidic. pH is measured on a logarithmic scale, where small changes have increasingly greater effects. A solution with a pH of 5 is ten times more acidified than a solution with a pH of 6 and 100 times more acidified than solution with a pH of 7.

Earth's oceans are naturally slightly alkaline. Historically, the pH of the surface ocean was approximately 8.1. Since the Industrial Revolution, the global average pH of the surface ocean has decreased by 0.11 pH units. This change may not seem like much, but because the pH scale is logarithmic, it represents a 30 percent increase in acidity. For more background information, check out “A Primer on pH” from NOAA’s PMEL Carbon Program.

Coastal Acidification

While ocean acidification is caused by the uptake of carbon dioxide (CO_2) from the atmosphere, coastal acidification is a slightly different mechanism. Near the coast, several other factors can contribute to even greater changes in ocean chemistry. The excess input of nutrients from shore (from fertilizers, wastewater, animal manure and more) promote acidification by stimulating algae growth. This in turn leads to intense respiration by animals that eat them, and the respiration drives up the local CO_2 concentration in the water. Along the West Coast of the US, coastal acidification can also be impacted by the process of upwelling. Deep waters that ‘rise up’ during upwelling are naturally enriched with CO_2 because respiration processes dominate in the deep. Deep waters are also enriched with excess (human-caused) CO_2 that was absorbed from the atmosphere when last in contact with the surface. Coastal acidification generally exhibits more variability over shorter time scales relative to open ocean acidification.

References

Center for Environmental Visualization and NOAA Pacific Marine Environmental Laboratory (PMEL) Carbon Group (2022). "A primer on pH," <https://www.pmel.noaa.gov/co2/story/A%2Bprimer%2Bon%2BpH>.

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Curriculum Structure and Standards

Scaled Structure

This game-based curriculum incorporates a scaled approach to learning. Each module offers activities at different levels of student interaction, specifically Knowledge and Comprehension, Application and Analysis, and Synthesis and Evaluation. The early levels are very directed and linear, which provides important first steps when learning something new. The levels of Application through Evaluation are more student-directed and foster opportunities to design lessons featuring student inquiry. The levels are designed to engage students in increasingly sophisticated modes of understanding and evaluation.

Ocean Literacy

This curriculum module supports the following Essential Principles of Ocean Sciences (Ocean Literacy Network, 2018).

1. The Earth has one big ocean with many features.

    e. Most of Earth's water (97%) is in the ocean. Seawater has unique properties. It is salty, its freezing point is slightly lower than fresh water, its density is slightly higher, its electrical conductivity is much higher, and it is slightly basic. Balance of pH is vital for the health of marine ecosystems, and important in controlling the rate at which the ocean will absorb and buffer changes in atmospheric carbon dioxide.

2. The ocean, and life in the ocean, shape the features of the earth.

    d. The ocean is the largest reservoir of rapidly cycling carbon on Earth. Many organisms use carbon dissolved in the ocean to form shells, other skeletal parts, and coral reefs.

5. The ocean supports a great deal of diversity of life and ecosystems.

    f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate, and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy." Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

6. The ocean and humans are inextricably interconnected.

e. Changes in ocean temperature and pH due to human activities can affect the survival of some organisms and impact biological diversity (coral bleaching due to increased temperature and inhibition of shell formation due to ocean acidification).

Next Generation Science Standards

This game-based learning program was developed to build data literacy, engaging students in increasingly sophisticated modes of understanding and manipulation of data. You can learn more about how this module relates to specific NGSS components with the detailed section Next Generation Science Standards Alignment. In addition, there is another detailed section Module Integration Example, which that shows how to integrate this game-based learning curriculum on ocean acidification into a module within a Biology, Chemistry or Environmental Science course.

Ocean Protector Lesson Plan

Objectives

Knowledge and Comprehension

- Learning Objective:
  - Students will understand that rising atmospheric CO_2 contributes to rising CO_2 concentrations in the ocean. Students will learn the likely effect of changes in CO_2 on ocean pH and acidification.
- Question Outcomes:
  - Conventional correct or incorrect answers on these questions, as they form the foundational knowledge and comprehension basis for the subsequent questions. Users will go through these 'tutorial' questions each time the game program is played, which reinforces learning. Ideally students will practice recall when going through this section again and be able to compete it more quickly on subsequent playthroughs. All users will see the same questions.

Application and Analysis

- Learning Objective:
  - Students will apply knowledge by answering questions and analyzing new data to understand the relationship between CO_2, pH, and ocean acidification.
- Question Outcomes:
  - Questions will not have an incorrect answer, and instead each option will have weights that affect the variables of the program. These questions will focus on applying understanding and analyzing ocean acidification decisions. Outcomes will be presented in real-time based on user choice. Many of these questions may be unique to an individual character.

Synthesis and Evaluation

- Learning Objective:
  - Students will continue answering more advanced question and synthesize ongoing ocean chemistry data and real-time feedback from biologic components to evaluate best decisions to reduce effects of ocean acidification.
- Question Outcomes:
  - Questions will not have an incorrect answer, and instead each option will have weights that affect the variables of the program. These questions will focus on synthesizing and evaluating more in-depth ocean acidification decisions. Outcomes will be presented in real-time based on user choice. Many of these questions may be unique to an individual character.

After completing their individual decisions, teachers can guide students to discuss and evaluate their decisions with classmates and be able to replay the experience. Ideally, this engaging learning experience will foster ocean literacy and stewardship, especially with students from inland communities who may not have engaged previously with these topics or with this form of learning and decision-making.

Background

As carbon dioxide (CO_2) dissolves into the ocean, a series of chemical reactions occur that result in the increased concentration of hydrogen ions and the reduction of pH. This process is called ocean acidification. pH is the measure of the hydrogen ion concentration in a solution. pH is used to express acidity or alkalinity on a scale of 0 to 14. Values above 7 are basic, or alkaline. Values below 7 are acidic. pH is measured on a logarithmic scale, where small changes have increasingly greater effects. A solution with a pH of 5 is ten times more acidified than a solution with a pH of 6 and 100 times more acidified than solution with a pH of 7.
Earth's oceans are naturally slightly alkaline. Historically, the pH of the surface ocean was approximately 8.1. Since the Industrial Revolution, the global average pH of the surface ocean has decreased by 0.11 pH units. This change may not seem like much, but because the pH scale is logarithmic, it represents a 30 percent increase in acidity.

While ocean acidification is caused by the uptake of CO_2 from the atmosphere, coastal acidification is a slightly different mechanism. Near the coast, a number of other factors can contribute to even greater changes in ocean chemistry. The excess input of nutrients from shore (from fertilizers, wastewater, animal manure and more) promote acidification by stimulating algae growth. This in turn leads to intense respiration by animals that eat them, and the respiration drives up the local CO_2 concentration in the water.

Coastal and shallow water ecosystems are some of the most productive ecosystems in the world. These areas support important fisheries that we rely on for food. Increases to OA can cause harmful effects on both marine life and the people that rely on those ecosystems for food and jobs.

The game-based learning tool that teaches students about OA, the effects on humans and marine life, and ways to help minimize the effects. Students will evaluate and select decisions based on the data provided and their own knowledge, and then they will analyze how their decision influenced OA impacts in real-time. This decision-driven experience helps students construct explanations, reason effectively, and become self-directed learners involving OA science and ocean literacy.

Materials

Each student will require a computer with an internet connection to access the online program.

Procedure

A summary of steps that the student user will complete consists of the following:

1. Students will open the program and select "New Game." They will then be prompted to enter a 4-digit number. This number will show on the Google Sheet Analytics page along with a game generated ID. Students can use the same number if desired because the game generated ID will be unique.

2. All students will go through the same preface lessons and answer the same questions, setting the groundwork for understanding basic topics.

3. Once successfully completed with the prerequisite lesson, the student will choose a character role, such as marine park ranger, fishing boat captain, or ocean tour guide. Background information for each character will be provided.

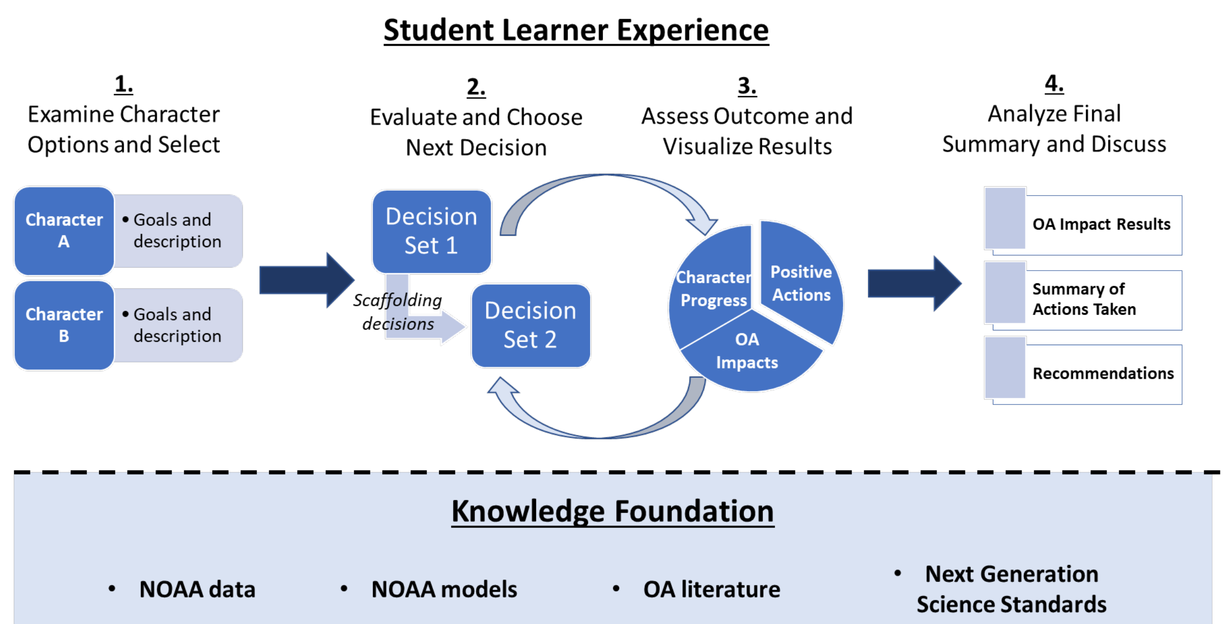
4. The game will then present a set of decisions—with some being more helpful to OA impacts than others. The student will evaluate the decisions based on the data provided and their own knowledge, then select an option. For the first decision, the game will guide them through the first decision process and how to interact and "play" the game.

5. Students will go through a series of decision choices and resulting outcomes, with each outcome showing the effect on the character's goal along with the overall score. At this point, scores that are assigned to questions will remain relatively straightforward (i.e., along a given numerical scale, how positive, net zero, or negative is this for reducing

CO2 and helping mitigate ocean acidity). The program will then automatically update OA outcomes and reveal to the student how that decision is affecting OA impacts for their character and marine life. Decisions will be engineered to engage students in increasingly sophisticated modes of understanding and help students construct explanations and become self-directed learners.

6. After a set number of decisions/turns has completed the students will be presented with a final summary visualization of their decisions, OA outcomes on their character, and recommendations. For example, if the student user selects decisions that are only strong positive actions throughout the game, then the final OA outcomes will be more favorable for their character and marine life.

7. After completing their individual decisions, students will discuss and evaluate their decisions with classmates and be able to replay the experience. Ideally, this engaging learning experience will foster ocean literacy and stewardship, especially with students from inland communities who may not have engaged previously with these topics or with this form of learning and decision-making.



Overall structure and outline for student experience in game-based learning curriculum.

Complimentary Material

Next Generation Science Standards Alignment

The game-based leaning curriculum presented here was developed to build data literacy, engaging students in increasingly sophisticated modes of understanding and manipulation of data. This document outlines the ways in which each level of the module provides learning experiences that engage students in the three dimensions of the NGSS Framework while building towards competency in targeted performance expectations. This document identifies the specific practice, core idea and concept directly associated with a performance expectation (shown in parentheses in the tables) but also includes additional practices and concepts that can help students build toward a standard.

Performance Expectations – Middle School
Earth and Human Activity NGSS MS-ESS3-3 Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment. Addressed By Students understand that rapid increases in atmospheric CO_2 have caused oceans to become more acidic and threaten marine ecosystems, and they test and evaluate decisions/methods to help reduce OA impacts on the environment.
Ecosystems: Interactions, Energy, and Dynamics NGSS MS-LS2-4 Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. Addressed By Students analyze quantitative results from game-based curriculum to show that coral reefs populations decrease with increasing OA, and that changes to coral also affects populations of other species such as fish and humans. NGSS MS-LS2-5 Evaluate competing design solutions for maintaining biodiversity and ecosystem services. Addressed By Students manipulate and discuss decisions to help reduce OA impacts on coral and coastal ecosystems, which have high biodiversity that is threatened by increasing OA.

Science and Engineering Practices (SEPs)	Middle School SEP	How the SEP is Addressed by the Module
Construction Explanations and Designing Solutions	Apply scientific principles to design an object, tool, process, or system. (MS-ESS3-3)	Students apply increasing levels of knowledge to test how decisions change marine systems and OA outcomes.
Engaging in Argument from Evidence	Construct an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. (MS-LS2-4) Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-LS2-5)	Students can have the option in the classroom to discuss and perhaps write summaries of their decisions to support ways to minimize OA effects on marine systems and people. Students evaluate and manipulate decisions that have varying means to reduce effects of OA.
Scientific Knowledge is Based on Empirical Evidence	Science disciplines share common rules of obtaining and evaluating empirical evidence. (MS-LS2-4)	Students visualize progress throughout their decision process and analyze how empirical outcomes can help inform future decisions.

Disciplinary Core Ideas (DCIs)	Middle School DCI	How the DCI is Addressed by the Module
ESS3.C: Human Impacts on Earth Systems	Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. (MS-ESS3-3) Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise. (MS-ESS3-3), (MS-ESS3-4)	Students analyze quantitative results from game-based curriculum to show that coral reefs populations decrease with increasing OA, and that changes to coral also affects populations of other species such as fish and humans. Students view that as OA will increase and harm marine systems and people unless certain decisions are assessed and applied to help prevent these negative effects.
LS2.C: Ecosystems Dynamics, Functioning, and Resilience	Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations. (MS-LS2-4) Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health. (MS-LS2-5)	Students understand that rapid increases in atmospheric CO_2 have caused oceans to become more acidic and threaten marine ecosystems in cascading ways. Students analyze and evaluate that biodiversity in marine systems decreases with decreasing ocean health due to harmful OA.
LS4.D: Biodiversity and Humans	Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling. (secondary to MS-LS2-5)	Students analyze quantitative results to show that important marine life such as coral reefs decrease with increasing OA, and that changes to these systems affects species that rely on those groups, such as fish and humans.

ETS1.B: Developing Possible Solutions	There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (secondary to MS-LS2-5)	Students analyze and assess multiple decisions in a cascading framework to evaluate best decisions to reducing the problem of OA.

Cross Cutting Concepts (CCCs)	**Middle School CCC**	**How the CCC is Addressed by the Module**
Cause and Effect	Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation. (MS-ESS3-3)	Students learn that increasing CO_2 is a causal mechanism for increasing OA.
Influence of Science, Engineering, and Technology on Society and the Natural World	The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus, technology use varies from region to region and over time. (MS-ESS3-2), (MS-ESS3-3), (MS-LS2-5)	Students will analyze and evaluate and decisions to reduce OA in various marine regions with different characters. This variation allows students to evaluate how different decisions lead to possibly varying outcomes in different marine regions.
Stability and Change	Small changes in one part of a system might cause large changes in another part. (MS-LS2-4), (MS-LS2-5)	Students assess and analyze that changes and decisions to one section of the marine system can have cascading effects to other sections of the system.
Science Addresses Questions About the Natural and Material World	Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes. (MS-LS2-5)	Knowledge that students gain through the curriculum can inform their decisions to help reduce OA as much as possible, though the real word decisions made by society my be different.

Module Integration Example

There are many ways to integrate this game-based learning curriculum on ocean acidification into a module within a Biology, Chemistry or Environmental Science course. One example, aimed at middle school teachers, is provided below.

Topic: Life Science

Grade level: Middle School (6th - 8th grade)

Example: This example of module integration uses a course model from the NGSS High School Phenomenon Model Course III – Bundle 3: Life Affects Earth.

NGSS Model Course 3 (Bundle 3): How can People Influence Earth?
MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystem services.
MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.
MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

Game-based learning program on ocean acidification can be integrated into a course sequence here, for more specific details see section on NGSS Alignment.

Game-based learning program on ocean acidification
Integrate part of the module into a sequence of lessons on ecology & biodiversity. Example phenomenon: * Different changes to ocean pH causing varying effects on marine life and the people that rely on those ecosystems.