DAY OF CLIMATE

Coastal Climate Science

Educator Guide

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Module Title Teachers' Guide

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Ms. Brancazio holds a BS in Electrical Engineering and Computer Science from Princeton University and an MS in Mechanical Engineering from MIT, and worked in product design at several engineering companies. Before returning to MIT she taught engineering design, computer science, technology education, and general science in public middle and high-school classrooms.

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Andrew Bennett has more than 35 years of R&D experience developing novel robot systems for land, water and air use. His projects include autonomous underwater vehicles at the MIT AUV lab, a full-sized walking quadruped robot technology demonstrator for Walt Disney Imagineering Research & Development, and the PackBot mobile robot system for iRobot. In 2011 Dr. Bennett became the Director of the SCOPE program at the Franklin W. Olin College of Engineering and taught Systems Engineering and Robotics. Currently he is Education Manager at the MIT Sea Grant College Program leading student research and projects related to marine environments, and underwater robotics. Dr. Bennett currently has four patents issued and five more pending. He holds a Ph.D. in Ocean Engineering from MIT, an M.S. in Mechanical Engineering Design from Stanford University, and a B.S. in Mechanical Engineering from MIT.

Introduction

MIT "Coastal Climate Science Activities and Experiments" (CCSAE) is a set of **hands-on experiments, real-life scenarios, academic references, and visualizations** that explain

and teach the interwoven connections between increased carbon dioxide in the atmosphere and the resulting harm to marine, terrestrial, and human life.

The overall goal is **for students to create the "big picture" of climate change for themselves**. Through a series of explorations, students learn the mechanisms and environmental phenomena, piece together the framework, and ultimately become more aware of the specific harm to marine and terrestrial life that increased atmospheric CO_2 is causing. With this understanding and knowledge, they will be **better prepared to make a positive difference in a world facing the challenges of climate change**.

This educational tool is designed to **explain environmental problems that students have most likely heard of**: rising sea level, ocean acidification, extreme and changing weather, harmful algal blooms, and changes to the Atlantic Ocean circulation. The learning experiences are quick, easy, qualitative, and impactful.

Target Age Range

- Recommended for students in middle school and high school (ages 12 - 18), though most of the resources on the site were created for the general public.

Run Time

- The CCSAE tool contains 40 activities organized around 5 climate-related environmental topics. Individual activities and experiments can be carried out in 20 to 50 minutes. Educators can focus on one environmental topic and tell its complete story in 2 to 5 class hours.

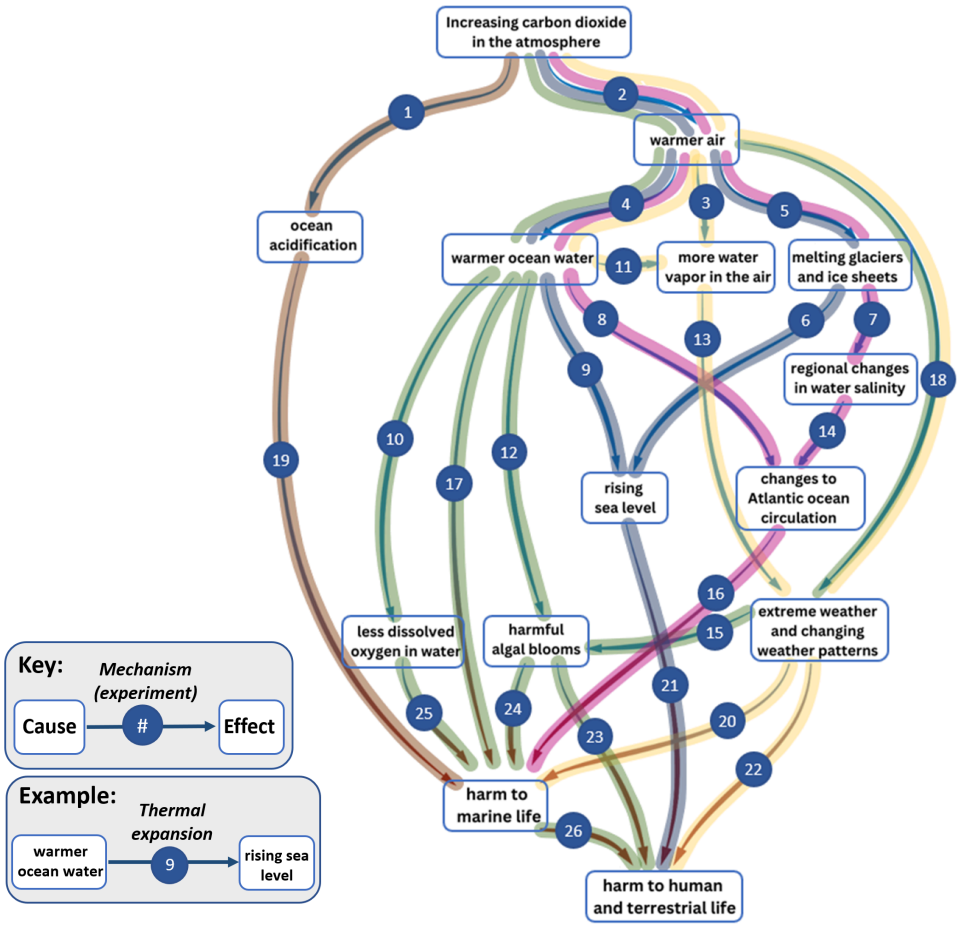
Activity Overview

Framework that illustrates climate change processes

The backbone of this tool is a novel **framework** that we created to illustrate the scientific connections between atmospheric carbon dioxide and harm to marine and terrestrial life (see image). Each of the five pathways documents a well-known environmental issue, showing how the problem is caused, how it is measured or studied, and how the ocean and related ecosystems are affected. The environmental issues in the pathways are:

- Rising sea level
- Changes to Atlantic Ocean circulation
- Extreme and changing weather
- Ocean acidification
- Poor water quality and harmful algal blooms

Cause-and-effect Framework



Each highlighted pathway consists of **text boxes** connected by **arrows**.

- The **text boxes are the "nouns"** labeling the **environmental conditions** that are occurring and have been scientifically documented.
- The **arrows are the "verbs"** representing the processes or mechanisms (physical, chemical, or biological) that connect Cause conditions to Effect conditions.
- The **number** on the arrow identifies an experiment or analysis that students carry out to see the mechanism in action.

How to use the CCSAE educational tool

This tool follows a constructivist model where students first learn by doing, then create a deeper understanding by seeking their own answers through research. The recommended way to use the CCSAE tool is also as an iterative process, where students do cycles of learning the mechanisms (natural processes), then learning about the environmental conditions that are caused. In this way they can build an understanding of the big picture of climate change, from increasing CO_2 in the atmosphere to changing conditions for ecosystems and life on Earth.

Recommended sequence:

1. The educator reviews the environmental issues addressed by the CCSAE and selects a **Pathway** based on student interest and/or relevance to their community.
2. At the selected Pathway page, educators review the hands-on learning experiences (**the Experiments and Analyses**) and the **suggested plan** for carrying them out. The **educator adapts the plan** to meet their time, material, and other constraints.
3. Students engage with the Experiments and Analyses to **see or get a feel for the mechanisms** (the physical, chemical and biological things that are happening).
    a. During the experiments, students observe what is happening and, in some cases, collect data. For the analyses, they read, watch or interact with online resources and look for a description or explanation of a process.
    b. At the end of the learning experience, they **draw a conclusion about the process** they observed or learned about, and **identify the mechanism** (physical, chemical, or biological process). They can compare their thoughts with the correct answers provided on the website (in collapsible boxes after the experiment or analysis).

4. To put the mechanism in the context of climate change, students **figure out which connection (arrow with #) on the framework** was demonstrated or described. That too, has a correct answer hidden in a collapsible box on the experiment/analysis page. This step is essential because it takes the mechanism from the world of science class and brings it onto the real world with real effects on an ecosystem or the life in it.

5. Students are then ready to **learn more about the environmental conditions at the cause and effect ends** of the connection arrow. For that they go to the **Environmental Explainer page**s, each of which has resources that address these questions: *What is it? How is it changing? Why does it matter?*

6. Educators can **continue on to the next experiment or analysis** (back to Steps 3, 4, 5), or go deeper into the key concepts on the existing steps, or wrap up the entire pathway with a reflection activity as they deem appropriate.

7. Complete the learning experience with a reflection that helps students put all the information together. The knowledge of the environmental processes and the resulting harm to ecosystems and life on Earth will be internalized differently by each student. There are resources on the site for actions and solutions as well as managing anxiety. Under Climate Change fundamentals, go to *Actions and Solutions* and *Why schools can't ignore it*.

Lesson outlines for each pathway are provided on the pathway pages. The outlines include all pathway elements and a suggested order for carrying them out. Shortened outlines are also provided. Educators are encouraged to adapt the lesson plans to meet their needs and constraints. The amount of time to take students through a pathway can be reduced by eliminating activities, combining them, or by leading them in direct instruction.

Sample sequence

Lesson Outline for Rising Sea Level Pathway.

Suggested order for all elements.
Adapt this to your own needs by eliminating activities or by leading them in direct instruction.
Note: If the experiment involves waiting, students can do an Environmental Explainer while it is going on.

Time	Experiment, notes and framework placement	Analysis, notes and framework placement	Environmental Explainer
30 min	Observe the greenhouse effect in a jar. (#2)		Increasing CO_2 in the atmosphere.

20 min			Warmer air
20 min		The impact of warmer air on the oceans (#4)	
20 min			Warmer ocean water
20 min		The impact of warmer air on glaciers and ice sheets (#5)	
20 min			Melting glaciers and ices sheets
40 min	Melting glaciers vs melting ice sheets (#6)		
40 min	Observe thermal expansion of water with a water bottle (9)		
20 min			Rising sea level
20 min		Investigate the impact that the rising sea level is having on land. (#21)	
20 min			Harm to human and terrestrial life

Total 4 hrs 30 min + Reflection

Shortened Lesson Outline for Rising Sea Level Pathway.

Suggested order for selected elements.

Time	Experiment, notes and framework placement	Analysis, notes and framework placement	Environmental Explainer
30 min	Observe the greenhouse effect in a jar. (#2)		Increasing CO_2 in the atmosphere.
~~20 min~~			Warmer air
~~20 min~~		The impact of warmer air on the oceans (#4)	
~~20 min~~			Warmer ocean water
~~20 min~~		The impact of warmer air on glaciers and ice sheets (#5)	
~~20 min~~			Melting glaciers and ices sheets
30 min	Combine Warmer air, Warmer ocean water, and Melting Glaciers and ice sheets into 1 lesson.		
40 min	Melting glaciers vs melting ice sheets (#6)		
40 min	Observe thermal expansion of water with a water bottle (9)		
20 min			Rising sea level
~~20 min~~		Investigate the impact that the rising sea level is having on land. (#21)	
20 min			Harm to human and terrestrial life

Total 3 hrs 0 min + Reflection

All activities

Experiments and Analyses are the arrows framework that refer to physical, chemical, or biological mechanisms. They can be thought of as “verbs” or actions. In these activities students either carry out an experiment or engage with online resources (video, article, visualization, infographics), with the goal of identifying a mechanism/process in the Cause and Effect framework.

Full list of Experiments and Analyses

Title of activity with connection #	time	level	Type of activity
Investigate dissolved carbon dioxide (CO_2) in water and pH (#1)	20 min	Beginner	experiment
Observe The greenhouse effect in a jar (#2)	30 min	Beginner	experiment
How temperature affects the water vapor capacity of air (#3)	30 min	Intermediate	experiment
The impact of warmer air on the oceans (#4)	20 min	All	analysis
The impact of warmer air on glaciers and ice sheets (#5)	20 min	All	analysis
Melting glaciers vs melting ice sheets (#6)	40 min	Beginner	experiment
The impact of additional fresh water on the ocean (#7)	30 min	Beginner	experiment
Changes in water density due to temperature (#8)	30 min	Intermediate	experiment
Observe thermal expansion of water (#9)	40 min	Intermediate	experiment
The effect of temperature on oxygen levels in water (#10)	20 min	All	analysis
Water vapor levels in air of various temperatures (#11)	30 min	Intermediate	experiment
The effect of temperature on algae growth (#12)	TBD	Advanced	experiment
The effect of increased water vapor on	20 min	All	analysis

weather events (#13)			
Changes in water density due to salinity (#14)	30 min	Intermediate	experiment
The effect of runoff on algae growth (#15)	TBD	Advanced	experiment
How changes in ocean currents affect marine life (#16)	20 min	All	analysis
How warmer water affects fish and other marine life (#17)	20 min	All	analysis
Extreme weather caused by extra heat (#18)	20 min	All	analysis
How ocean acidification harms corals and other marine life (#19)	20 min	All	analysis
Damage to undersea life from hurricanes and extreme weather events (#20)	20 min	All	analysis
The impact that the rising sea level is having on land (#21)	20 min	All	analysis
The impact that extreme weather is having on land (#22)	20 min	All	analysis
How toxic algae can harm humans (#23)	20 min	All	analysis
Harm to ocean ecosystems from larger and more frequent algal blooms (#24)	20 min	All	analysis
The effects of low dissolved oxygen levels on marine life (#25)	20 min	All	analysis
How humans depend on the oceans and marine life (#26)	20 min	All	analysis

Environmental Explainers are the text boxes on the framework that refer to environmental conditions. They can also be thought of as “nouns” or situations. In these activities students engage with a video, article, visualization or infographics to answer these questions: *What is it? How is it changing? Why does it matter?*

Full list of Environmental Explainers

Environmental condition	**Time for activity**
Warmer ocean water	20 min
More water vapor in the air	20 min

Melting glaciers and ice sheets	20 min
Ocean acidification	20 min
Rising sea level	20 min
Regional changes in water salinity	20 min
Changes to Atlantic Ocean circulation	20 min
Extreme and changing weather	20 min
Less dissolved oxygen in water	20 min
Harmful algal blooms (HABs)	20 min
Harm to marine life	20 min
Harm to human and terrestrial life	20 min

Learning Goals

Relevant standards from NGSS and Common Core are included in each Experiment and Analysis lesson plan on the site.

In general there are physical, chemical and biological sciences as well as research and analysis of resources:

Common Core State Standards Connections:

ELA/Literacy

WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

WHST.11-12.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

Mathematics

WHST.9-12.9 Draw evidence from informational texts to support analysis, reflection, and research.

HSF-IF.C.7 Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases. (HS-PS2-1)

HSS-ID.A.1 Represent data with plots on the real number line (dot plots, histograms, and box plots)

HSN-Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
MP.2 Reason abstractly and quantitatively.
MP.4 Model with mathematics.

NGSS standards

HS.Energy

HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*
HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

HS.Life Sciences
HS.Matter and Energy in Organisms and Ecosystems
HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere
HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.
HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
HS-LS2-8. Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.
LS2.A: Interdependent Relationships in Ecosystems
LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
LS2.C: Ecosystem Dynamics, Functioning, and Resilience
LS2.D: Social Interactions and Group Behavior
HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.
LS4.C: Adaptation

Disciplinary Core Ideas
ESS2.D: Weather and Climate
ESS3.A: Natural Resources
ESS3.B: Natural Hazards
ESS3.C: Human Impacts on Earth Systems

ESS3.D: Global Climate Change

HS.Earth's Systems

HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

Materials

Educators using this tool are not expected to be experts or science teachers, and may well be learning along with the students. Many of the experiments can be done with kitchen and craft supplies, a few use inexpensive scientific tools, and none require the use of sophisticated equipment or a special lab. A complete list of materials for all experiments is linked on the site under Educator Resources.

Materials for most of the experiments are very basic and can be found in a kitchen or home workshop.

- Glass bowls and measuring cups ½ liter, 1 liter, 2 liter
- Measuring spoons
- Salt
- Food coloring
- Plastic drinking straws
- Clear plastic food storage bags
- Rubberbands
- Glass jars such as grocery jars (peanut butter, pickles, etc) or mason jars
- Electric kettle
- Oven mitts
- Sealing putty or Blu-Tack adhesive
- Waterproof Digital Meat Thermometers
- Electric drill and drill bits
- CO_2 bicycle tire inflator or SodaStream carbonator
- Clear plastic containers as from fruit or vegetables
- Work lamp with light socket, aluminum reflector, clamp and 150 watt bulb

A few items are less common but can be easily purchased at a craft store, hardware store, or online:

- Clear plastic film canisters with lids, ~ $ 24 for 120 on Amazon
- Clear PVC flexible tubing, 1/8" ID x 3/16" OD, 10 feet, ~ $ 8

For pH testing the following technical items are useful:

- Bromothymol Blue, 0.04% Solution 60ml, in dropper bottle, ~ $ 12
- PH test strips 1-14, ~ $ 6

For salinity experiments the following technical item is useful but not necessary:

- Refractometer for Seawater 0-100 PPT, ~$ 18

For the 2 algae growth experiments, the following supplies are needed:

- Mini digital temperature humidity meters with probe, 3/pk, ~ $ 10
- Algae Research Supply Algae Culture, Six Strains, ~ $ 33
- Concentrated Guillard's F2 Formula, 8 oz, ~ $ 17
- Cotton Cheese Cloths, 36×36 inch, ~ $ 6
- Miracle-Gro Indoor Plant Food, 8 oz, ~$ 7
- LED Grow Light Strip Kit 45W, 16 Inches, 4/pk,~ $ 32
- Portable hard cooler, 16 Quart
- Ice Packs for Coolers

Document resources

For teachers:

- Lesson Plan - Rising Sea Level.pdf
- Lesson Plan - Atlantic Ocean circ.pdf
- Lesson Plan - Extreme Weather.pdf
- Lesson Plan - Ocean Acidification.pdf
- Lesson Plan - Water Quality.pdf
- Lesson Plans-all.pdf

For students:

- Sea Level worksheet.pdf
- Ocean Circ worksheet.pdf
- Extreme weather worksheet.pdf
- Acidification worksheet.pdf
- Water quality worksheet.pdf
- student worksheets-all.pdf

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