SUSTAINABLE DEVELOPMENT GOALS

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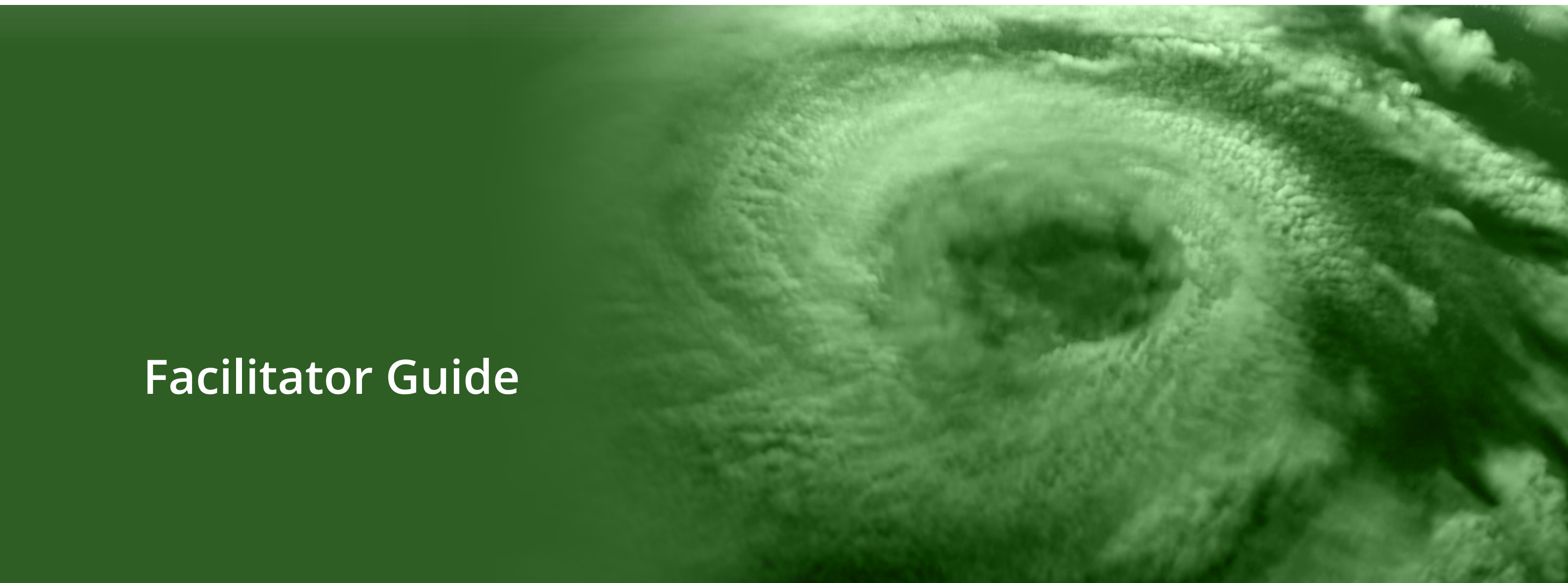
Education for Sustainable Development Kit: Impacts of Climate Change

13 CLIMATE ACTION

Sustainable Development Goal 13: Climate Action



Facilitator Guide

Education for Sustainable Development Kit: Impacts of Climate Change

Sustainable Development Goal 13: Climate Action

Facilitator Guide

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ESD KIT: IMPACTS OF CLIMATE CHANGE

Sustainable Development Goal 13: Climate Action

INTRODUCTION

ESD Kit Strategy

Young learners can be inspired to take an active role in promoting sustainable development in their communities. The Education for Sustainable Development (ESD) Kits will help learners build knowledge about important topics that affect all communities and individuals. Unlike past versions of ESD Kits, which were developed as stand-alone activities, ESD Kits are designed to promote sustained attention to a topic and the development of multi-faceted understanding.

Each kit consists of Investigations that are presented in a variety of engaging formats. The focus topics addressed in the ESD Kit Investigations are closely aligned with the United Nations Sustainable Development Goals (SDGs) on which each kit is based. The knowledge that learners develop about the SDGs will bring light to local issues and will prepare them for community awareness and engagement.

UN Sustainable Development Goal (SDG) → Learning Experiences: Investigations & Project → Community Awareness & Engagement

The first four ESD Kits are currently in development. Each focuses on one SDG:

SDG 6: Clean Water and Sanitation

SDG 7: Affordable and Clean Energy

SDG 12: Responsible Consumption and Production

SDG 13: Climate Action

Learning outcomes for the kits address ideas in the SDG targets, as well as the relevant UNESCO **Education for Sustainable Development Goals: Learning Objectives**.

Learning Progression

Each ESD Kit provides multiple opportunities for learner engagement across a range of learning styles, interests, and skill levels. Each kit starts with an Investigation in which learners reflect on their own relationship with the topic of the SDG — such as their energy use or how they may be affected by climate change. In the remaining Investigations learners will explore different aspects of the topic. The activities in the ESD Kits may make use of one or more active learning approaches, including:

- Hands-on learning
- Data-focused analysis
- Computer coding by designing or repurposing projects in *Scratch*®
- Applications of microprocessors for sensing and control, and for data logging
- Strategies for communicating with others about ideas, problems, and solutions

Across these approaches, learners have opportunities to practice 21st Century Skills such as critical thinking, communication, and information literacy. Each ESD Kit includes a project that allows students to synthesize ideas, relate them to their community, and share them with peers.

Materials

The ESD Kits are designed to be implemented across the world, using materials that are expected to be readily accessible in different international contexts. The material lists in the facilitator guides include specific details about the items to be used. Whenever possible, Investigations use materials and supplies that are familiar and easy to acquire locally. Investigations using more technical items, such as microprocessors, also provide less technical options that address the same concepts.

Uses of *Scratch*® and Microcontrollers

The ESD Kits incorporate the use of *Scratch*®, a widely available, free programming environment that is implemented in dozens of languages and has user support documentation available in many of them. In the ESD Kits, coding is also used with microprocessors (e.g., micro:bit) to support two broad focus areas — technological literacy and creative self-expression.

Computer-based technologies affect every person and society in ways that are direct and other ways that are indirect. Citizens of the future need to understand basic computer processes such as coding to control and automate systems. This understanding is an important aspect of technological literacy and is a foundation for further learning in computer science and other technologically sophisticated fields.

As well, *Scratch*® provides an open-ended but well-supported set of tools for learners to model, explore, and present their ideas about the topics they are learning about in the ESD Kits in creative and technologically advanced ways. Included are many examples of *Scratch*® projects that can inspire learners and/or be the basis of their own work. Presentations provide a way for the learners' ideas to be clarified, validated, and appreciated by a range of audiences, including their peers, their parents, and other community members.

Extensions

Each Investigation has at least two Extension activities that build on or supplement the concepts covered as learners complete the procedure and analysis questions. There are four categories of Extension activities. *Testing Variables* allows learners to explore additional variables that could be tested within the procedure or a related experiment. *Analyzing Data* has learners describe and explain trends in graphs, maps, and data tables. *Applying Concepts* asks learners to use the main concepts covered in the Investigation to make sense of other phenomena, technologies, or issues. Lastly, *Using Scratch* gives learners ideas for how to make interactive computer-based presentations, stories, and games related to the Investigations. The Extensions are meant to give learners a more complete understanding of the concepts covered. Although they are optional, they are highly recommended.

Facilitator Support

The ESD Kits have been developed by experienced educators and curriculum designers to provide the support needed for facilitators to be successful. At the same time, the guidance in the kit is flexible enough to allow facilitators to respond to their learners and communities by adapting Investigations — such as by accessing locally relevant data, applying ideas to examples that are known to the children, and providing opportunities for learners to creatively express their own ideas in multiple formats, including through *Scratch*® programming.

The facilitator support includes such key elements as:

- An overview that briefly presents key concepts and descriptions of each Investigation.
- A master list of materials, organized by Investigation.
- Detailed step-by-step guidance for facilitating learner participation in each Investigation.
- Photographs of key stages within Investigations.
- Conceptual background needed to guide learners.
- A pacing guide to help facilitators estimate the time each Investigation may take.
- Extension opportunities, guidance connecting each Investigation to the project.
- Questions to consider with learners--and possible responses.
- "Notes for the Facilitator" that point out instructional options and fine points.
- Guidance on the use of microprocessors and *Scratch*®.

With these support features, facilitators will find the ESD Kits useful to inspire the next generation of community problem solvers, whether or not they've worked in education and outreach before.

Partnership Model

ESD Kits will be implemented by Schlumberger employees working in collaboration with partners in their locations. These partners may come from a variety of areas of expertise and may play any of several roles in the implementation. Examples of partnerships include:

- Educators in the community facilitating specific ESD Kit Investigations, or whole kits.
- Specialists working in areas of the community related to the ESD Kit, such as managers of local water facilities (SDG 6), power plants (SDG 7), retail shops (SDG 12), architectural design firms (SDG 13), to offer learners a real-world perspective on the dynamics of the topics as they affect the learner's community.
- Community members/organizations working on projects that make positive changes in the community that relate to one or more of the SDGs (e.g., recycling).

Inspiring Action

Overall, the intent of the ESD Kits is to inspire and enable young people to take action in their homes and communities. Through active learning, effective facilitation, and strong community partnerships, the ESD Kits can play a role in building a positive and sustainable future for all.

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OVERVIEW FOR THE FACILITATOR

In this ESD Kit, learners will explore aspects of climate that are changing most rapidly and how human activity is influencing these changes. This ESD Kit focuses on the Key Concepts of the *Targets and Indicators* within **Sustainable Development Goal (SDG) 13:** Take urgent action to combat climate change and its impacts.

This ESD Kit was designed using a "**systems thinking**" approach. Climate change is described in terms of a global ecological system, which includes aspects of climate and how they shape environments in different parts of the world, as well as how they affect other Earth systems. Most of the attention in the ESD Kit is on the movement of carbon between systems due to its ability to affect change in each of those systems.

Data-focused Investigations are used to call attention to broader features of climate and the causes of climate change. Hands-on Investigations are used to learn about mitigation and adaptation strategies for reducing the impacts of climate change on the environment and humans. Some Investigations also include opportunities to use technologies for sensing and coding, using the coding language *Scratch*®.

ESD Kit Project: Design a Resilient City

Learners will complete Investigations to learn about climate change. They will then complete a culminating ESD Kit project in which they will use what they have learned to design a city that has specific features that make it more resilient to environmental changes such as sea level rise or acid rain. Learners will prepare a presentation that outlines the decisions they made about design features of the city, and the climate-related rationales for those decisions. Their presentation will relate the features of their building to Key Concepts of SDG 13.

Key Concepts

Several Key Concepts for this ESD Kit have been summarized from the SDG 13 Targets and Indicators. Added to those are other Key Concepts that students will need to know to understand fundamental ideas about climate. The Key Concepts for this ESD Kit are: *adaptation strategies, adaptive capacity, carbon sink, climate, climate change, climate change measures, climate-related hazard, early warning, greenhouse gases, impact reduction, mitigation, resilience, risk-reduction strategy.*

Investigation Descriptions

Key concepts are in italics.

1. **Considering Climate.** Key Concepts: *climate*

   Learners describe weather and how it differs from *climate*. They will analyze maps and graphs to describe the components of different climates, including their own. Discussion of learners' ideas will build a foundation for understanding climate. The United Nations' Sustainable Development Goal 13 is introduced as an overarching theme of the ESD Kit, which looks at how people can reduce carbon emissions and take other actions to slow climate change and reduce its effects.

2. **Greenhouse Gases and Climate.** Key Concepts: *climate change, greenhouse gases, impact reduction*

   Learners will use a model to study the structure of carbon dioxide and oxygen, focusing on the differences that lead to carbon dioxide being classified as a *greenhouse gas*. Facilitator demonstrations will illustrate ways in which carbon dioxide is transferred between Earth systems. Data analysis introduces learners to the idea of *climate change* to recognize that it is, in large part, due to the increase in the concentration of atmospheric carbon dioxide and that *impact reduction* is dependent on decreasing carbon emissions.

3. **Measuring Carbon Dioxide and Acidity.** Key Concepts: *climate-related hazard, greenhouse gas, impact reduction, mitigation*

   Learners complete a number of hands-on activities to understand how carbon dioxide affects the pH of water and how an increase in temperature affects the ability of water to hold carbon dioxide. Analysis of data will allow an understanding of the global effects of acid rain and increasingly acidic bodies of water. Learners will analyze how carbon capture can be a means of *impact reduction* and *mitigation* in terms of reducing the effects of *climate-related hazards* that have a direct link to an increase in atmospheric carbon dioxide.

4. **The Heat Capacity of Water and Coastal Storms.** Key Concepts: *adaptation strategies, climate, climate change, climate-related hazards, impact reduction*

   Learners conduct an experiment to compare the rate at which various liquids heat up. Analysis of maps introduce learners to how *climate change* is causing oceans to warm. Coastal storms will be investigated as a *climate-related hazard*. Learners design *adaptation strategies* to test *impact reduction* of coastal storms.

5. **Ice Melting, Thermal Expansion, and Sea Level Rise.** Key Concepts: *early warning, mitigation, risk-reduction strategy*

   Learners conduct hands-on activities to understand how climate change and sea level rise are related. Data analysis then highlights the importance of recognizing *early warning* indicators as a sign to implement *mitigation* and *risk-reduction strategies.*

6. **Measuring Albedo and Albedo Enhancement.** Key Concepts: *adaptation strategies, climate change measures*

   Learners measure albedo and associated temperature changes. This Investigation also provides an opportunity to use micro:bit to automatically log temperature changes. Learners then measure the albedo and temperature of common construction materials to assess the use of *climate change measures* in the planning of a human-made structures and cities as an *adaptation strategy* for reducing atmospheric warming.

7. **Assessing Soil Health and Sustainable Farming Practices.** Key Concepts: *adaptive capacity, carbon sink, resilience*

   Learners will test their local soil to understand the components of soil, as well as attributes that allow a soil to be described as having a high *adaptive capacity* that allows them to be resistant or reactive to climate change. Data analysis will allow learners to describe the ability of soil to act as a *carbon sink* that can remove carbon dioxide from the atmosphere and therefore contribute to the *resilience* of ecosystems.

ESD KIT:
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MASTER LIST OF MATERIALS

Investigations are intended to be completed in small groups. Materials used in multiple Investigations are marked with asterisks.

Materials by Investigation:

Investigation 1: Considering Climate

Per group:

- maps
- graphs

Investigation 2: Greenhouse Gases and Climate

For Facilitator Demonstrations:

- 1* lighter
- 1 candle
- 1** small piece of foil
- 4 test tubes or glass vials
- 1† pipette
- 1‡ straw
- 1§ small plastic cup
- 100 craft pom poms (5 colors)
- 1 plastic sandwich bag
- tongs or heat-resistant gloves
- scissors
- ‡ bromothymol blue or other pH indicator solution
- ◊ safety goggles

- plastic wrap or tape to cover vials

For Learner Investigation:

Per group:

- 9§ plastic cups
- 1 marker
- 1¶ 100 mL graduated cylinder
- 1*** pipette
- 1 oxygen molecular model (2 tennis balls, 15 cm [6 in] flexible tubing)
- 1 carbon dioxide molecular model (3 tennis balls, 2 25 cm [10 in] pieces of flexible tubing)
- water
- duct tape or plasticine clay
- *Also used in Investigation 4B

**Also used in Investigation 6A2

†Also used in Investigations 3A and 4A

‡Also used in Investigation 3A

§Also used in Investigations 3A and 7A

◊Also used in Investigations 4A, 4B, and 7A

¶Also used in Investigation 7A

Investigation 3A: Measuring Carbon Dioxide and Acidity

For Facilitator Setup:

- 1‡ alcohol thermometer
- jars containing §vinegar and an item (eggshell, leaves, paper clips, apple slice, etc.)

For Group A:

- 2† small plastic cups
- 1§ small cup of apple cider or white vinegar
- 1 petri dish or similar clear, shallow dish with a cover
- 2* pipettes or medicine droppers
- 1 toothpick
- 1 timer, stopwatch or clock with a second hand
- water
- pH paper
- ** bromothymol blue or other pH indicator solution
- camera (optional)

For Group B:

- 2† small plastic cups
- 1** straw
- salt water
- water
- ** bromothymol blue or other pH indicator solution

For Group C:

- 1 500 mL graduated cylinder or clear water bottle

- 1 plastic funnel with a short stem
- 1 plastic bin or bowl (10-15 cm [4-6 in] deep)
- cold water (approximately 10oC [50oF])
- warm water (approximately 20oC [68oF])
- hot water (approximately 30oC [86oF])
- sodium bicarbonate tablets (effervescent antacids, such as Alka-Seltzer®)
- tape
- food coloring (optional)

For Group D:

- 1* pipette or medicine dropper
- 1 mortar and pestle (or another tool that can safely crush the chalk)
- 1 petri dish or plastic food container
- § apple cider or white vinegar
- chalk (cannot be dustless chalk or molded chalk)

*Also used in Investigations 2 and 4A

**Also used in Investigation 2

†Also used in Investigation 2 and 7A

‡Also used in Investigations 4A, 5A, and 6A1

§Also used in Investigation 7A

Investigation 3B: Analyzing Greenhouse Gas Emissions

Per group:

- copies of graphs within the Investigation

Investigation 4A: Testing the Heat Capacity of Liquids

For Facilitator Demonstration:

- 2* pipettes or medicine droppers
- water
- isopropyl alcohol or hand sanitizer (minimum 70% alcohol)
- dark, waterproof surface (desk, chalkboard, or other relatively impervious surface)
- ** safety goggles
- sunny area (or bright lamp) (optional)
- timer or stopwatch (optional)
- For Learner Investigation:

Per group:

- 1 250-500 mL (1-2 cup) heat-resistant glass measuring cup (or beaker)
- 1 plate or tray to carry measuring cup
- 1† alcohol thermometer
- 1 hotplate (or microwave)
- 1 small towel
- 100-250 mL (½-1 cup) water, oil (e.g., vegetable, olive, peanut), and liquid soap
- boiling stones (if using a microwave, to prevent superheating)
- oven mitts
- ** safety goggles

- *Also used in Investigations 2 and 3A

**Also used in Investigations 2, 4B, and 7A

†Also used in Investigations 3A, 5A, and 6A1

Investigation 4B: Coastal Storms

For Facilitator Demonstration:

- 2 balloons (30 cm [12”] diameter)
- 1* lighter
- 1 large basin or plastic bin
- water
- ** safety goggles
- For Learner Investigation:

Per group:

- 1 clear plastic bin
- 1 empty 500 mL (16.9 oz) water bottle
- 1 ruler
- water
- small dowels, toothpicks, popsicle sticks, small rocks, or other seawall materials
- construction paper
- tape
- washable markers (different colors)
- metronome (or recording of a steady beat)
- modeling clay
- For Group A:
- fine-grained sand

For Group B:

- pebbles or coarser sand

*Also used in Investigation 2

**Also used in Investigations 2, 4A, and 7A

Investigation 5A: Ice Melting, Thermal Expansion, and Sea Level Rise

For Facilitator Demonstration:

- 1 500 mL Erlenmeyer flask
- 1 rubber stopper with two holes (that fits flask)
- 1 piece of thin glass tubing (must fit in rubber stopper)
- 1* alcohol thermometer (must fit through one hole of the rubber stopper)
- 1 desk lamp with incandescent bulb (or area with direct sun)
- 1 ruler
- 1 fine tip, black permanent marker
- cold water
- food coloring (optional)

For Learner Investigation:

Per group:

- 1 plastic bin

- 1 closed cell foam block (approximately half the height and length of the bin)
- 1 desk lamp
- 1 washable marker
- 1 ruler
- saltwater
- large ice block containing food coloring
- weight (optional)
- mass scale (optional)
- *Also used in Investigations 3A, 4A, and 6A1

**Also used in Investigation 7B

***Also used in Investigations 3B, 4, and 7B

Investigation 5B: Mitigation of Coastal Flooding

Per group:

- graphs
- maps
- calculator (optional)
- *Also used in Investigations 2B, 3A, and 5A

Investigation 6A1: Albedo

Per group:

- 3 pieces of paper (white, black, and another color)
- 4 pieces of cardboard
- 4** alcohol thermometers
- 1 light meter
- 1 timer
- * foil
- sunny area (or desk lamp)
- tape (optional)
- *Also used in Investigation 2

**Also used in Investigations 3A, 4A, 5A

Investigation 6A2: Logging Temperature Automatically Using a micro:bit

Per group:

- 3 pieces of paper (white, black, and another color)
- 3 pieces of cardboard
- 1 micro:bit V2 (some other micro:bits do not support data logging)
- 1 3 V battery pack for the micro:bit
- 1 laptop or computer
- 1 light meter
- 1 timer
- sunny area (or desk lamp)
- tape (optional)
- *Also used in Investigations 7A and 7B

Investigation 6B: Albedo Enhancement

Per group:

- 1 shallow tray or pan
- 1 infrared thermometer
- 1 desk lamp with an incandescent bulb (preferably 100 W)
- 1 light meter
- pieces of construction material (brick, concrete, wood, roofing, siding)
- natural materials (sand, soil, grass, leaves)
- cardboard (optional)
- sunny area (optional)

*Also used in Investigations 7A and 7B

Investigation 7A: Assessing Soil Health

For Facilitator Demonstration and Setup:

- 1 soil sampler/corer
- locally sourced soil
- pint-sized glass jar with a lid
- water

For Learner Investigation:

Per group:

- 1 annual plant or grass grown in local soil with roots intact
- 1 small plastic bin or paper plate
- 1 teaspoon
- 1 magnifying glass
- 4 plastic water bottles (or other clear, narrow containers)
- 1 gravel
- 1 trowel
- 1 spray bottle filled with water
- 1 bucket
- 1 ruler
- 1† 100 mL graduated cylinder
- 1 soil testing kit (for nitrogen, phosphorous, and potassium)
- 3* plastic cups (200 mL [1 cup])
- locally sourced soil (approximately 100 mL [1 cup] per group)
- bagged garden soil (approximately 100 mL [1 cup] per group)
- tap water
- distilled water
- ‡ vinegar
- baking soda
- sand
- pH test paper (if not in soil testing kit)
- ** safety goggles
- *Also used in Investigations 2 and 3A

**Also used in Investigations 2, 4A, and 4B

†Also used in Investigation 2

‡Also used in Investigation 3A

Investigation 7B: Sustainable Farming Practices

- copies of graphs from the Investigation

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INVESTIGATION 1: CONSIDERING CLIMATE

Facilitator Background

Connection to SDG 13: Indicator 13.3.1 aims to increase the "extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in national education policies [and] curricula" (https://sdgs.un.org/goals/goal13). This introductory Investigation clarifies the differences between weather and climate to prompt learners to consider how climate impacts their region. Further Investigations will build off this understanding of climate to look at how humans have affected it, and how changes can be made to move toward sustainability.

Key Concepts: *climate*

Learning Outcome: Explain the difference between weather and climate to understand how each affects your community.

Connection to the ESD Kit Project: Design a Resilient City: Learners will redesign an existing city or will design a new city with specific adaptations or mitigation strategies to reduce the impact of climate-related hazards. Understanding climate and how it is changing is vital to knowing what and how climate-related hazards could affect their city.

Notes for the Facilitator: If planning to complete the entire ESD Kit, it is a good idea to introduce the ESD Kit Project to learners during this Investigation. The ESD Kit Project revisits the major concepts in each Investigation that can be used in a city designed with specific climate change adaptation strategies or structures. Introducing the ESD Kit Project now would allow learners to think about their city designs in advance of starting the project.

PACING GUIDE

PREPARATION
20 minutes reading the facilitator notes

WHAT TO DO
20 minutes discussing the introduction material
45 minutes for the Investigation

Materials

Per group:

- Handout- Maps and Graphs

What to Do

Notes for the Facilitator: Questions are also on the Learner's Version of this Investigation.

1. Look outside and describe current weather conditions.

Notes for the Facilitator: Answers will vary but can include relative amounts of sunlight, precipitation, wind, and temperature.

2. Describe different weather conditions you've experienced in your area. Why does weather vary throughout the year?

Notes for the Facilitator: Prompt learners to consider all possible weather conditions, including seasonal storms that occur in your area (e.g., hurricanes, tornadoes). Weather varies with seasons.

3. What are the seasons like where you live? Describe any seasonal changes that occur.

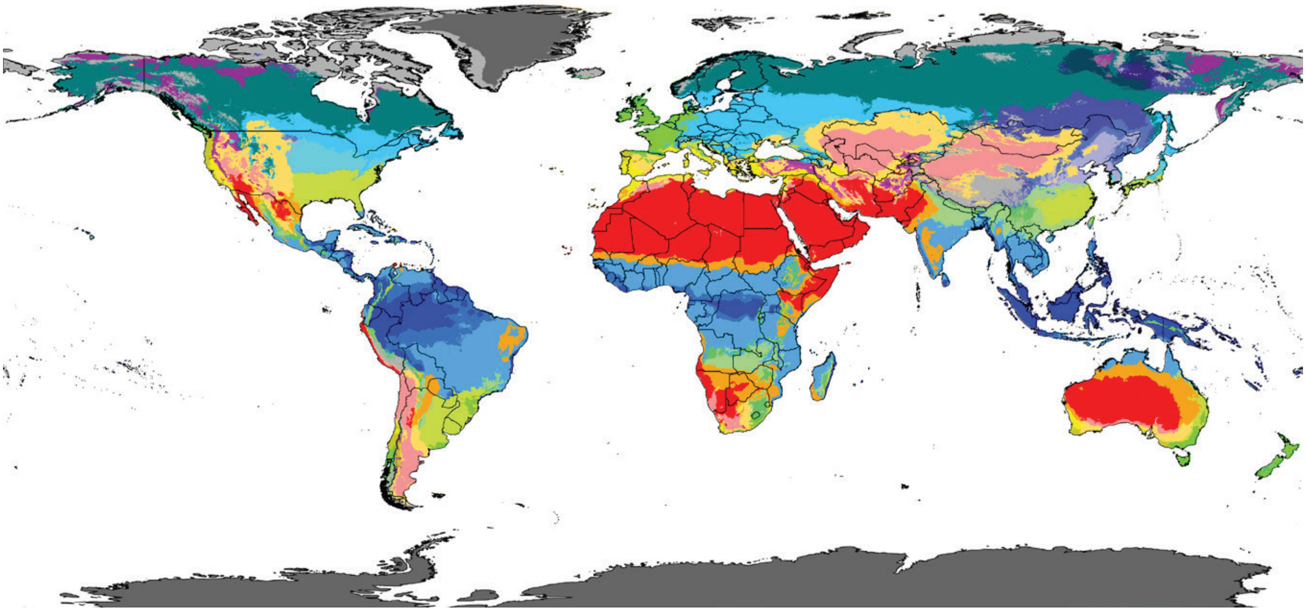
Notes for the Facilitator: Regions near the equator will experience fewer seasonal changes than regions in middle or upper latitudes. Different parts of the Earth get varying amounts of sunlight, which causes changes in wind patterns. More information on seasons can be found here: **https://www.nationalgeographic.org/encyclopedia/season/**. Regions near the equator will have higher average temperatures. Areas between the equator and about 30o north or south are more likely to experience seasonal monsoons. Colder temperatures and snow are more likely at both higher latitudes and altitudes.

4. Describe any weather conditions you have seen or heard about in other areas that do not happen where you live. Why does the weather vary from region to region?

Notes for the Facilitator: Due to differences in the amount of sunlight received in different locations, there will also be differences in wind patterns, water currents, temperature, and precipitation. All these factors vary in broadly predictable trends over the course of a year and so occur in an expected pattern, which we call climate. There are other contributing factors, such as how close a city is to large bodies of water, as well as their altitude.

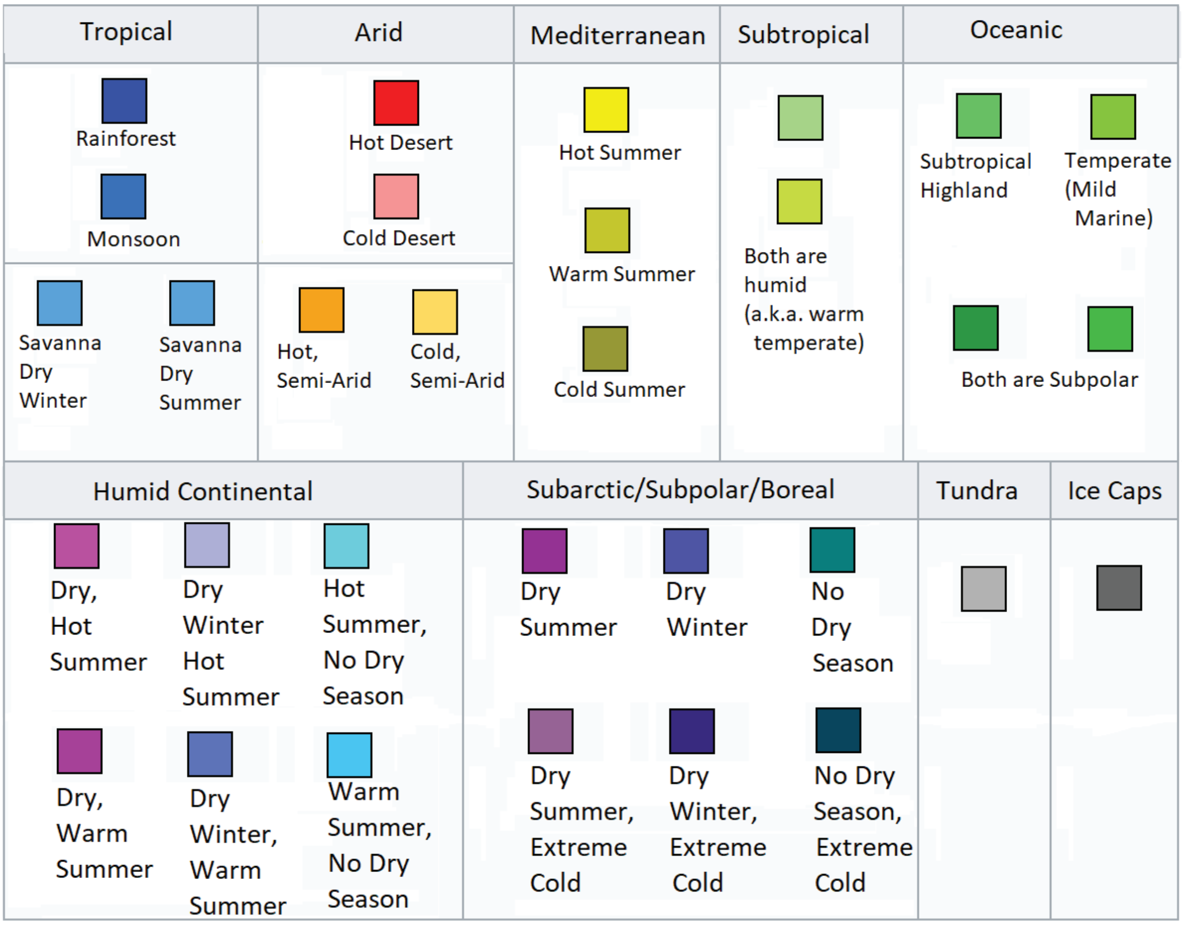
5. Locate your region on the map and identify your region's climate.

Köppen–Geiger climate classification map (1980–2016)



Credit: Beck et al., https://upload.wikimedia.org/wikipedia/commons/d/d5/K%C3%B6ppen-Geiger_Climate_Classification_Map.png

Köppen-Geiger Climate Classification Key



Credit: modified from Beck et al., https://upload.wikimedia.org/wikipedia/commons/d/d5/K%C3%B6ppen-Geiger_Climate_Classification_Map.png

Notes for the Facilitator: If you are not able to print in color, use the link to access the image online.

6. Talk with a partner about a type of environment (desert, forest, grassland, etc.) that is common in your region given its climate. What features does it have?

   a. Draw a picture of that environment. Include some organisms you would expect to find there.

   b. Describe how this environment fits the description of the climate in your area that is given on the map. What elements of the climate are not described well by the map?

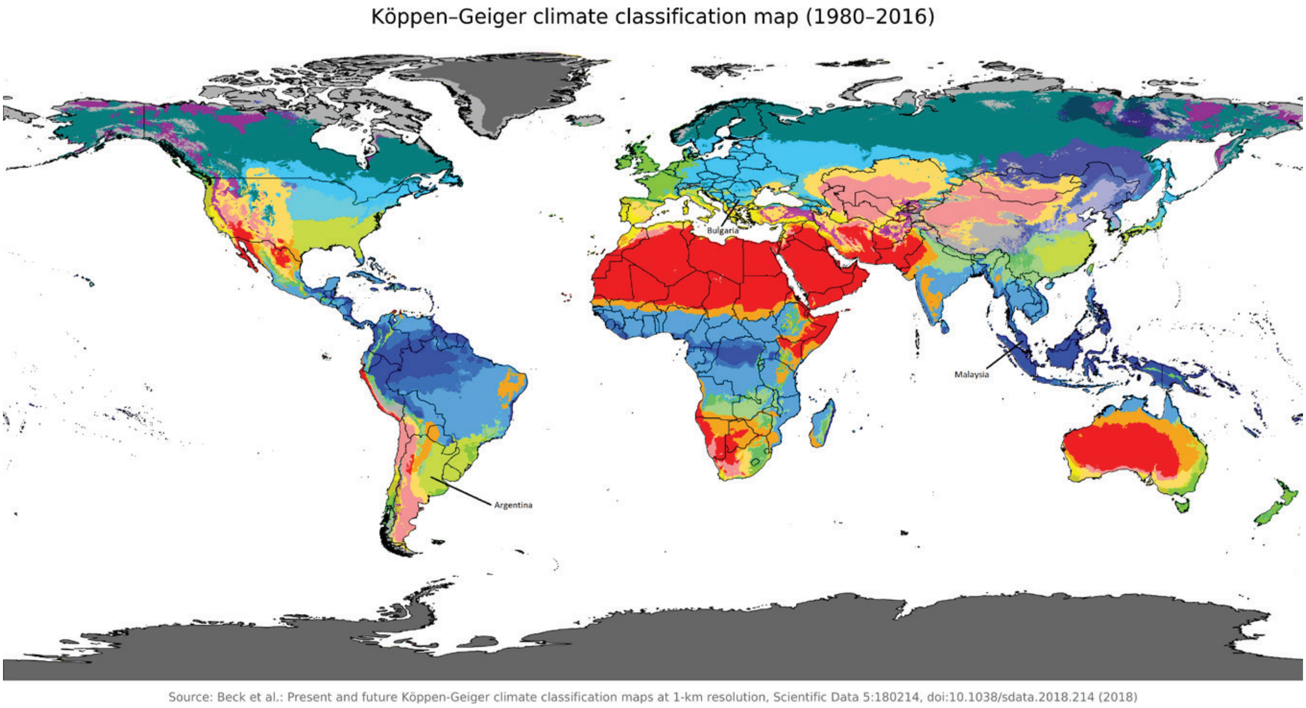
Notes for the Facilitator: Answers will vary but should connect the amount of sunlight and precipitation to how the environment looks and what living things are found there. Specific weather events and conditions are not shown by the map, such as storms and seasonal changes. The map also does not show how each area may have changed over time.

7. Describe any trends you see in the locations of different climates, identified by the colors on the map.

Notes for the Facilitator: Certain environments (colors) are common along the same latitude (distance from the equator). Deserts (shades of red) and rainforests (dark blues) occur frequently around the equator. Humid continental environments (light blues) are common at mid-latitudes above and below the equator. Tundras and ice caps (greys) only occur at very high latitudes (near each pole) or in large mountain ranges. Where a country is located on a continent also affects climate. Deserts tend to be more toward the western part of a continent. Humid continental areas tend to be toward the eastern part of a continent. This is because climate is also affected by how close an area is to large bodies of water and mountain ranges, elevation, and the direction of the prevailing winds (i.e., what temperature and how much humidity the winds tend to bring in).

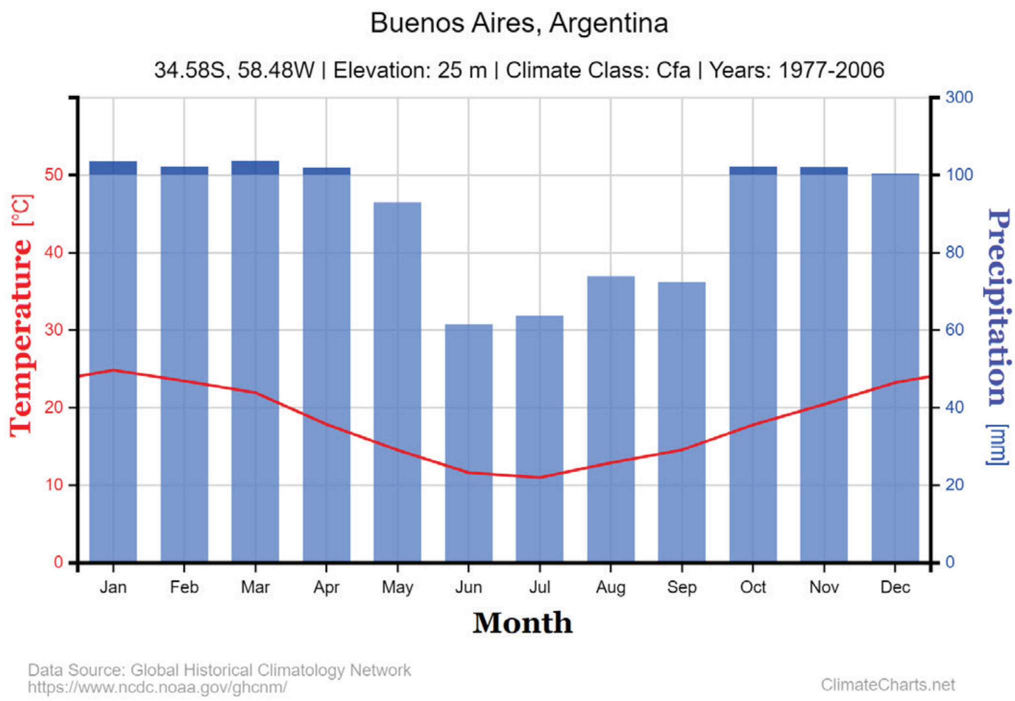
8. Locate the following countries on the climate map: Argentina, Malaysia, and Bulgaria. Identify their climates.

Notes for the Facilitator: The following map shows the countries labeled.

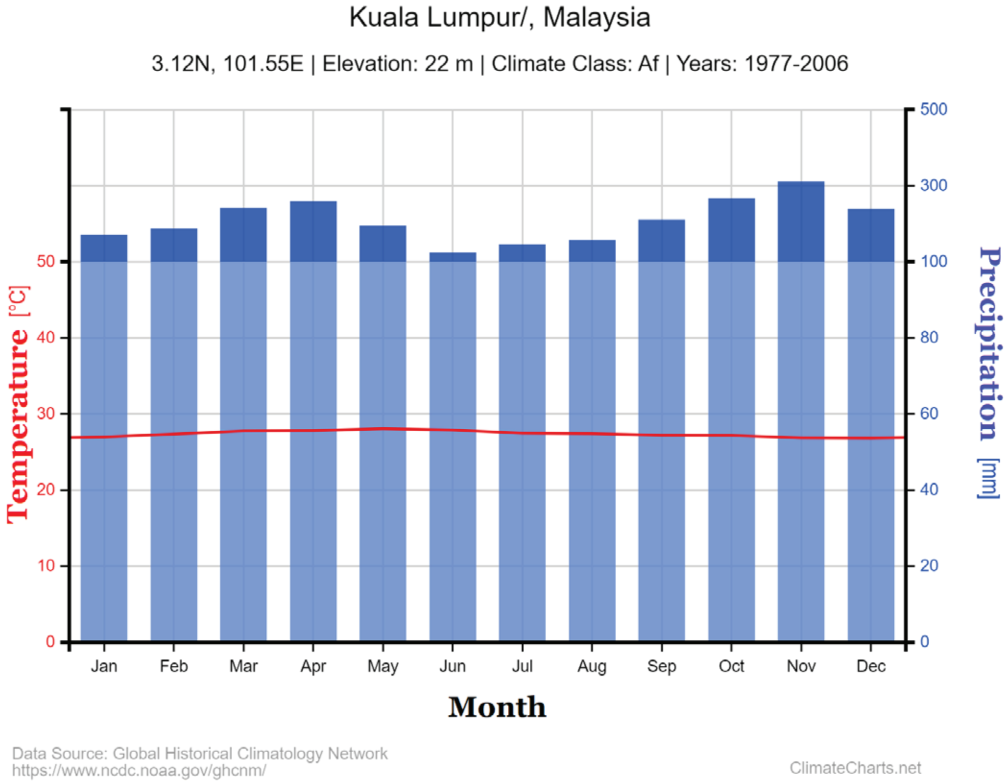


Credit: Modified from Beck et al., https://upload.wikimedia.org/wikipedia/commons/d/d5/K%C3%B6ppen-Geiger_Climate_Classification_Map.png

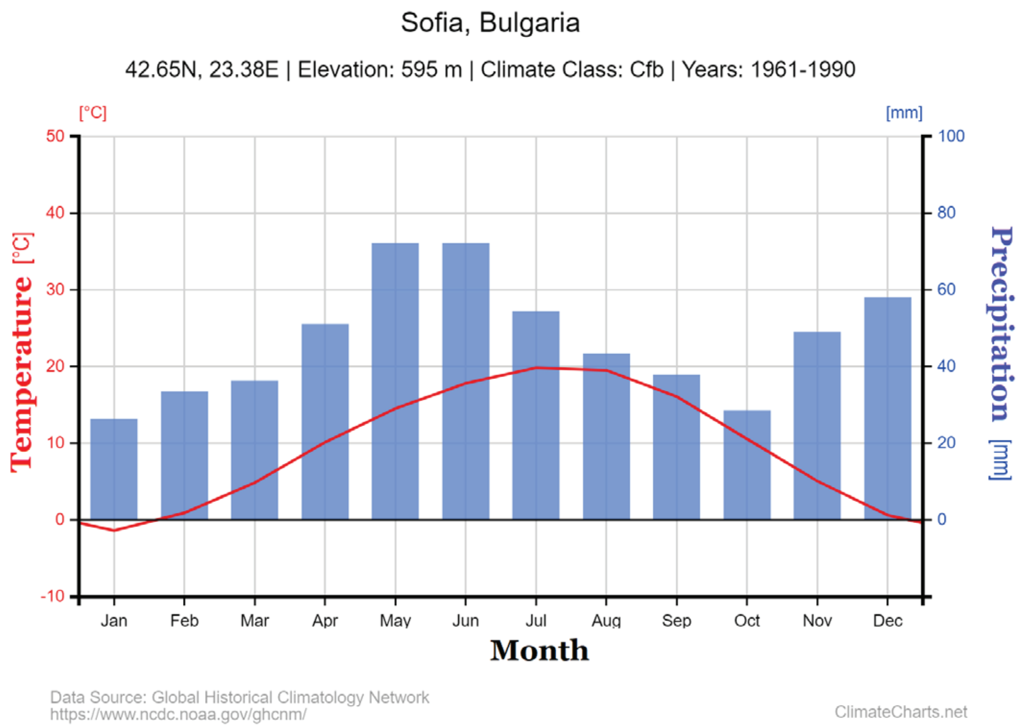
a. A climatogram includes a line graph of the average monthly temperatures in degrees centigrade (°C) and a bar graph of the average monthly precipitation in mm. Examine the climatograms below and describe each city's trends in average temperature and precipitation.



Credit listed with third graph.



Credit listed with third graph.



Credit: Modified from aura Zepner, Pierre Karrasch, Felix Wiemann & Lars Bernard (2020) ClimateCharts.net — an interactive climate analysis web platform, International Journal of Digital Earth, DOI: 10.1080/17538947.2020.1829112

Notes for the Facilitator: Buenos Aires, Argentina, has the highest average temperatures between December and February, which is summer in the southern hemisphere. Average temperatures are above freezing all year but have a range (11–25 °C). Precipitation is at or above 100 mm every month between October and April.

Kuala Lumpur, Malaysia, has little variation in average monthly temperatures (28–29 °C). Precipitation is also consistent, with over 100 mm average every month of the year.

Bulgaria has a wide range of average monthly temperatures, from −2 °C in January to 20 °C in July. Note that the trend in temperature is opposite that of Argentina, since Bulgaria is in the northern hemisphere, while Argentina is in the southern hemisphere. May and June have the highest average precipitation, approximately 72 mm, and December has the next highest, with 59 mm. Due to freezing temperatures, it is likely that some of the winter precipitation is snow.

For learners who need assistance with reading climatograms, here is a good resource: **http://www.cotf.edu/ete/modules/msese/earthsysflr/climograph.html**

b. How can the trends on the climatograms be used to describe the climate of each city?

Notes for the Facilitator: While each country has multiple possible climates, there is one climate that best matches their climatograms. For learners who need descriptions of different climates, see: **https://www.nationalgeographic.org/article/all-a bout-climate/** A particular climate is defined by its average temperatures and precipitation. For example, Kuala Lumpur, Malaysia, has a rainforest climate due to a high average year-round temperature and many rainy days. The climatogram for Buenos Aires, Argentina, matches subtropical, which has moderate to high temperatures and a lot of rain. The climatogram of Kuala Lumpur, Malaysia matches Rainforest, which is expected to have consistently high temperatures and rainfall. The climatogram of Sofia, Bulgaria matches Humid Continental with No Dry Season because it has moderate temperatures and consistent, moderate levels of rainfall.

c. Use this information to predict some other cities that you would expect to have climatograms like that of Buenos Aires, Kuala Lumpur, and Sofia.

Notes for the Facilitator: To find cities with similar climates, you could look along the same latitudes as these countries or use the climate map to find countries with the same color code. Rainforests are most common around the equator and occur in countries such as The Democratic Republic of Congo, Indonesia, and northern Brazil. Buenos Aires' climatogram would be like the southeastern portions of the United States and China. The climatogram of Sofia, Bulgaria climatogram would match that of most of eastern Europe, as well as many cities in Sub-Saharan countries, such as Nigeria, Ghana, and Tanzania.

d. Explain why climatograms cannot be used to predict weather on a particular day.

Notes for the Facilitator: Climatograms are made based on averages (trends) of temperature and precipitation taken over many years. There are days when temperature and precipitation will be out of the expected range, and the average does not necessarily describe any specific day. Have a group discussion to ensure there is a clear understanding of the difference between weather and climate. Discuss answers to these questions. End the discussion by introducing learners to the United Nation's Sustainable Development Goals and specifically SDG 13 on Climate Action (**https://sdgs.un.org/goals/goal13**).

9. Sustainable Development Goal (SDG) 13 is all about climate change and the many impacts it has on the environment.

a. What do you think about when you hear "climate change"?

b. What do you think some of the environmental impacts of climate change are?

c. Why do you think addressing climate change is important for people around the world?

Notes for the Facilitator: A good resource that reviews the impacts of climate change is: **https://climate.ec.europa.eu/climate-change/consequences-climate-change_en**. After introducing SDG 13 to learners and discussing the questions above, discuss the Targets and Indicators within SDG 13 and their importance in terms of access to clean water. If possible, have learners read through the SDG Targets and discuss which the learners consider most important and why.

Consider

1. Can the trends on the climatogram be used to determine the exact location of a city? Why or why not?

Notes for the Facilitator: No. Certain climates are common along specific latitudes but do have variations due to their exact location. Proximity to large bodies of water can affect climate. Also, some ecosystems have similar climatograms that might be misleading, such as areas on the top of mountains having a tundra-like climate even if the mountains are not located in upper latitudes.

2. Consider the climates of the three cities, Sofia, Bulgaria, Kuala Lumpur, Indonesia, or Buenos Aires, Argentina.

a. Do these three cities experience the same seasons at the same time? Give evidence from the climatograms to support your answer.

Notes for the Facilitator: No. Buenos Aires has lower temperatures in June, July, and August, which is when their winter is, while Sofia has lower temperatures in December and January. Kuala Lumpur does not seem to have distinct seasons, as its temperature and precipitation stay relatively constant throughout the year.

b. Climatograms do not specify the type of precipitation a city receives. Do you think any of these cities get snow? What makes you think this?

Notes for the Facilitator: The average temperature is at or below freezing some months in Sofia, Bulgaria. This likely indicates that some of their precipitation is snow or freezing rain.

c. For each of these three cities, name the months when it would be most appropriate to wear "summer" clothing. Are they the same months for all three cities? Explain your answer.

Notes for the Facilitator: The hottest months in Buenos Aires are December through January; for Sofia are June through September; and every month for Kuala Lumpur. These are not the same times of the year because of where each city is located. Kuala Lumpur is near the equator, Buenos Aires is in the southern hemisphere, and Sofia is in the northern hemisphere. Sofia, Bulgaria, likely has a greater temperature change throughout the year than Buenos Aires because Sofia is farther from the equator. Also, Sofia is inland, while Buenos Aires is near the ocean, which likely helps moderate its climate.

d. Consider outdoor activities you enjoy doing. Which of these three cities could you most likely visit or live in and be able to do these activities? Give evidence from the climatograms to support your answer.

Notes for the Facilitator: Answers will vary based on the learners' interests.

3. Predict what a climatogram for your city would look like. Use what you know about your country's climate to describe what the trends for temperature and precipitation may look like.

Notes for the Facilitator: Answers will vary. It is suggested you have a copy of the climatogram for your city to either complete the extension or to discuss.

Extensions

1. **Testing Variables:** Build a weather station to better understand variables involved in weather and to be able to distinguish it from climate.

2. What variables will you measure? What equipment would you need to measure each of these factors? How often would you take data? How will you analyze and use the data from your weather station?

3. Many automatic sensors and microcontrollers, such as micro:bit, can be used to not only sense variables related to weather, but can also log data at regular intervals set by the user. Kits are available to make a weather station using a micro:bit: https://bit.ly/microbitweatherstation and https://www.sparkfun.com/products/16274. What are the advantages of having a microcontroller log data? What might be some disadvantages?

4. **Applying Concepts:** Look at a climatogram from your city.

   a. Compare your climatogram to those from Buenos Aires, Argentina, Kuala Lumpur, Malaysia, and Sofia, Bulgaria. Which of the three climatograms is most like yours? Describe the similarities and differences.

   b. Which of the three climatograms is most different from yours? Why does this make sense given where in the world these countries are found?

Notes for the Facilitator: Climatograms for specific cities can be generated at: https://climatecharts.net/ Click on a city, then click Create Charts. Answers for these questions will vary based on location.

ESD KIT:
IMPACTS OF CLIMATE CHANGE

13 CLIMATE ACTION

Sustainable Development Goal 13: Climate Action

INVESTIGATION 2: GREENHOUSE GASES AND CLIMATE

Facilitator Background

Connection to SDG 13: Indicator 13.2.2 states that countries should institute measures regarding "total greenhouse gas emissions per year" (**https://sdgs.un.org/goals/goal13**). Carbon dioxide, methane, and nitrous oxide are the three main greenhouse gases contributing to climate change. Greenhouse gases are the primary factor causing global temperatures to rise. Reducing greenhouse gas emissions, especially from the combustion of fossil fuels, is one method of impact reduction — a way to prevent further warming of the Earth's atmosphere and other effects that come from the accumulation of greenhouse gases. This Investigation focuses on the structure and exchange of carbon dioxide and how it impacts climate.

Key Concepts: *climate change, greenhouse gases, impact reduction*

Learning Outcome: Investigate carbon dioxide as a molecule by studying the atmosphere and how carbon dioxide is exchanged between Earth's systems.

Connect to the ESD Kit Project: Design a Resilient City: Climate is affected by the amount of greenhouse gas emissions from natural and human-made causes. Learners can design a city that has a low level of greenhouse gas emissions to reduce further climate change.

PACING GUIDE

PREPARATION

15 minutes setting up Step 3 (three days in advance)
10 minutes setting up Step 4 (one day in advance)
20 minutes setting up materials for groups

WHAT TO DO

5 minutes discussing the Introduction
5 minutes for Facilitator Demonstration 1
10 minutes for Facilitator Demonstration 2
30 minutes for the Investigation

Introduction

Earth's atmosphere is made up of about a dozen gases. The table shows the approximate percentages of the major gases in the atmosphere:

Atmospheric Gas	% of the Atmosphere
Nitrogen	78.084%
Oxygen	20.946%
Argon	0.9340%
Carbon Dioxide	.0407%
Other	.00268%

Data source: https://climate.nasa.gov/news/2915/the-atmosphere-getting-a-handle-on-carbon-dioxide/

Gases that contribute to the warming of the atmosphere are called greenhouse gases. These are naturally occurring gases, and it is beneficial that they warm the atmosphere; however, even a small change in the concentration of any of these greenhouse gases can have a major impact on the temperature of Earth's atmosphere. Carbon dioxide is the most abundant greenhouse gas, but the Other category in the table also includes methane and nitrous oxide, which are also contributors to atmospheric warming.

Notes for the Facilitator: Discuss with learners what they know or have heard about the gases listed on the table. You can use colored pom poms to make a visual representation of the relative concentration of the gases in the atmosphere. Choose a different color pom pom for each gas. There will be 78 Nitrogens, 21 Oxygens, 1 Argon, a smaller pom pom can be used one for Carbon Dioxide, and an even smaller pom pom of a fifth color for the Other category. Lay the bag flat on a table so learners can view it. Alternatively, you can have learners set up this representation. The Extension at the end of this Investigation has an option for learners to set this up and to compare Earth's atmospheric gases with those of other planets.

Materials

For Facilitator Demonstrations:

- lighter
- candle
- small piece of foil
- 4 test tubes or glass vials
- pipette
- bromothymol blue (available in many aquarium test kits, or other pH indicator with a color change scale, such as red cabbage juice)
- straw
- small plastic cup
- safety goggles
- plastic wrap or tape to cover vials in learner step 3

- 100 craft pom poms or similar (1.2 cm [.5 in] diameter, 5 colors)
- scissors
- 1 plastic sandwich bag
- tongs or heat-resistant gloves

For Learner Investigation (per group):

- 9 plastic cups
- 1 marker
- water
- 100 mL graduated cylinder
- pipette
- 1 oxygen molecular model (2 tennis balls, 15 cm [6 in] flexible tubing)
- 1 carbon dioxide molecular model (3 tennis balls, 2 25 cm [10 in] pieces of flexible tubing)
- duct tape or plasticine clay

What to Do

Facilitator Setup for Learner Investigation step 2:

1. Prepare a soil sample and setup to collect carbon dioxide three days prior to learners completing the Investigation. On the day of data collection, it is recommended you make another setup without the sugar solution so they can see what it looks like initially, and then can compare that to the final color of the solution.
2. Cut a plastic bottle about ¼ of the way down. Leave a small portion intact so you can bend it back the top of the bottle, but do not remove it completely.
3. Fill the bottle 1/3 full with soil and add 20 mL of water. Tap the bottle on a hard surface to get the soil to settle to the bottom of the bottle.
4. Mix 60 mL of water with 5 g of sugar.
5. Fill the bottle to 2/3 full with soil, then add 30 mL of the sugar mixture.
6. Fill the bottle to the cut rim and add another 30 mL of sugar mixture.

Credit: L.C. Mossa

7. Flip the top of the bottle down and secure it with waterproof tape, such as duct tape.
8. Insert one end of the plastic tubing into the bottle and secure it with tape (or plasticine clay), ensuring that its end rests right near the top of the soil in the bottle. Use tape to completely close off the lid of the bottle.

9. In a small clear container mix 25 mL of water with 10 drops of bromothymol blue.

10. Insert the other end of the plastic tubing into the container with the bromothymol blue mixture so that the tubing is submerged in the solution.

Credit: L.C. Mossa

11. Secure the tubing with tape, completely closing off the lid of the container.

12. Allow this setup to sit for 3 days before learners view it. After three days, the color in the small container will change to teal, green, or yellow, depending on the level of activity (respiration) of the microbes in the soil. Teal indicates a moderate level of activity, green and yellow indicate high levels of soil respiration. If the solution does not change at all, it could be due to a lack of soil microbes, indicating poor soil health. A lack of color change could also be due to lack of a tight seal where the tubing enters the containers.

Credit: L.C. Mossa

Facilitator Setup for Learner Investigation Step 3:

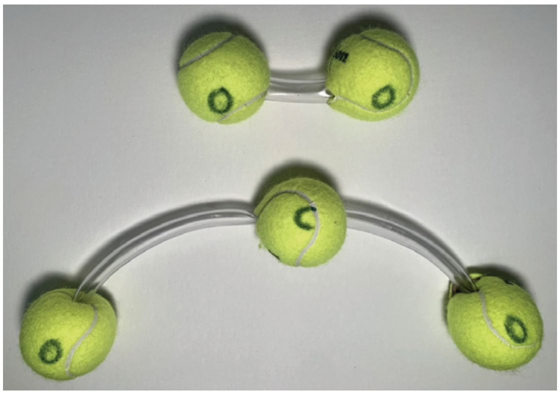
1. Prepare a solution of water, bromothymol blue, and carbon dioxide.
   a. Make enough solution to fill 3 test tubes approximately ¾ full.
   b. Use 10 drops of bromothymol blue per 50 mL of water, then use a straw to exhale into the solution until it is yellow.
   c. Pour an equal amount of this solution into the 3 test tubes; then use the descriptions in Learner Investigation Step 3.a. to complete setups ii-iv at least one day before learners observe them.
2. Prepare test tube i as a control.
3. Cover the top of all 4 test tubes with plastic wrap or tape.
4. Wrap test tube iv completely with foil. Place all 4 tubes under a lamp for at least 24 hours.
5. It is important to let the test tubes sit under light overnight so that results are noticeable.

Learner Investigation:

1. The Structure of Atmospheric Gases

   a. Examine how oxygen and carbon dioxide react to solar energy using a model. Hold the model of the oxygen molecule by one end and gently shake it. The shaking represents solar energy being added to the molecules. Observe the tubing holding the tennis balls together. The tubing represents the bond between the oxygen atoms, which are represented by the tennis balls.

Notes for the Facilitator: These models are based on those found here: **https://cleanet.org/resources/58183.html.** Label the tennis balls: O for oxygen and C for carbon. We built the models using the same tubing for the bonds, but the bond in the oxygen molecule is short enough that it is stiff, while the bonds in carbon dioxide are long enough to be flexible. The same would be true if nitrogen gas (N_2) was being modeled, as nitrogen is also rigid and not considered a greenhouse gas. The flexibility of the models is the most important feature to have.



Credit: L.C. Mossa

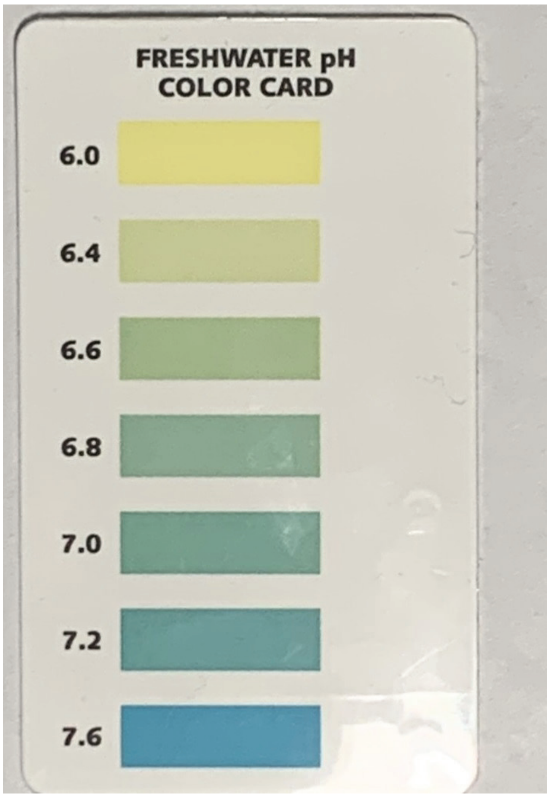
   b. What do you notice when you shake the model?

   c. Repeat this with the model of the carbon dioxide molecule. What do you notice when you shake the model? How is it similar or different to the oxygen model?

Facilitator Demonstration, Part 1:

1. Fill a small plastic cup with 100 mL of water and ten drops of bromothymol blue. Stir or gently swirl the solution for 5 seconds.

2. Use a color chart to estimate the pH of the water.



Credit: L.C. Mossa

3. Use a pipette to draw up approximately 3 mL of the bromothymol blue solution from the vial to be used in the second Facilitator Demo.

4. Tell learners that you will be exhaling into the solution through a straw. Ask learners "What is 'in' an exhale?"

5. Have learners predict what will happen if you exhale into the bromothymol blue solution.

6. Use a straw to blow into the solution. Exhale through the straw slowly so that your breath creates bubbles in the bromothymol blue. Keep taking breaths and exhaling them through the straw until the bromothymol blue turns green and then yellow.

Notes for the Facilitator: Discuss that carbon dioxide is one of the gases they exhale. There are also gases dissolved in water, including oxygen, and carbon dioxide. Carbon dioxide will interact with the water making a weak acid (carbonic acid), which lowers the pH.

Learner Investigation:

1. Carbon Exchange with the Soil
    a. Observe the experimental setup of a bottle of soil that has been running for approximately 3 days. The soil in the bottle was mixed with sugar water at the beginning of the experiment. Gases were collected from soil during those three days. The gases were funneled into a container of bromothymol blue that was mixed with water. The bromothymol blue in the small container was in its blue (neutral) state at the beginning of the experiment.
    b. Use the color chart to determine the approximate pH of this solution now.
2. Carbon Exchange and Plants
    a. The test tubes are filled with the solutions below and have been sitting under a lamp for the last 24 hours. Observe the color of the test tubes.
        i. Bromothymol Blue in water (control)
        ii. Bromothymol Blue in water with carbon dioxide added
        iii. Bromothymol Blue in water with carbon dioxide and a plant added
        iv. Bromothymol Blue in water with carbon dioxide and a plant added, covered with foil (dark)

Facilitator Demonstration, Part 2:

Notes for the Facilitator: Have the pipette containing the bromothymol blue solution collected during the first Facilitator Demonstration ready. Caution: Proper safety precautions should be taken when using a flame. Protective equipment such as tongs, heat-resistant gloves, and heat-resistant glass should be used.

1. Light a candle and using tongs or a heat-proof glove hold a dry lab-glass (e.g., Pyrex) vial inverted over top of the flame for one minute. The vial should be close to the flame, not completely covering it.
2. Have learners predict which gas they think the candle gives off: oxygen or carbon dioxide. They should also predict if and what color change they might observe in the bromothymol blue when the gas from the candle is added to the solution.
3. Quickly flip the glass vial upright and use a pipette (from Facilitator Demonstration, Part 1) to add the bromothymol blue solution to the vial.
4. Cap the vial with a small piece of foil and gently rotate the liquid for 5 seconds to mix the gas into the liquid. The top of the vial may be hot, so be careful not to touch it or wear gloves to protect your hands.
5. Use the color chart to estimate the pH of the liquid in the vial.

Consider

1. How did the models of oxygen and carbon dioxide react differently when shaken? How do you think the shapes of these molecules affect their ability to absorb solar energy?

Notes for the Facilitator: The oxygen model was very stiff and did not bend when shaken. When oxygen molecules are exposed to solar energy, they do not absorb much of it and are relatively unaffected. The same is true for other molecules with two atoms and a single bond like nitrogen, or gases that are single atoms, like helium or argon. The carbon dioxide model was very flexible, and its bonds bent when shaken. When carbon dioxide molecules are exposed to solar energy, they readily absorb it. This is why carbon dioxide is considered a greenhouse gas since it absorbs heat and holds onto it in its flexible bonds. The absorption of energy by carbon dioxide contributes to the greenhouse effect.

2. The solution connected to the bottle of soil started out blue. Determine how much the pH changed over three days.

   a. What gas did the soil give off? How can you tell?

Notes for the Facilitator: The change in pH will vary but can be determined by the color chart for the pH indicator you used. The pH change indicates that the soil gave off carbon dioxide, because the bromothymol blue changed from blue to green or yellow (depending on your soil or setup). This is the same change shown when you exhaled carbon dioxide into the solution during the demonstration.

   b. How do you think carbon gets into the soil?

Notes for the Facilitator: Answers will vary based on learner's backgrounds. Plants and decomposition will add the most carbon to soil.

3. Compare the colors of each of the test tubes.

Notes for the Facilitator: The expected colors are:

i Bromothymol Blue in water = blue

ii Bromothymol Blue in water with carbon dioxide added = green or yellow

iii Bromothymol Blue in water with carbon dioxide and a plant added = blue

iv Bromothymol Blue in water with carbon dioxide and a plant added, covered with foil (dark) = yellow or green

   a. Describe the purpose of the test tubes i and ii.

Notes for the Facilitator: These are controls to see that nothing else influenced the solutions other than the plants inside vials iii and iv.

   b. Which gas does photosynthesis produce? How can you tell?

Notes for the Facilitator: Oxygen is produced by photosynthesis. This is evident when the solution in test tube iii changed back to blue in the light, indicating the plant gave off oxygen. The plant also consumed carbon dioxide in the solution, which contributed to the color change back to blue.

   c. Which gas does cellular respiration produce? How can you tell?

Notes for the Facilitator: Carbon dioxide, because the solution remained green or yellow in test tube iv. The plant could not do photosynthesis due to lack of light. The plant can always do respiration using stored sugars, releasing carbon dioxide as it does. Also, during respiration the plant consumes oxygen which removes it from the water and causes the solution to remain green or yellow.

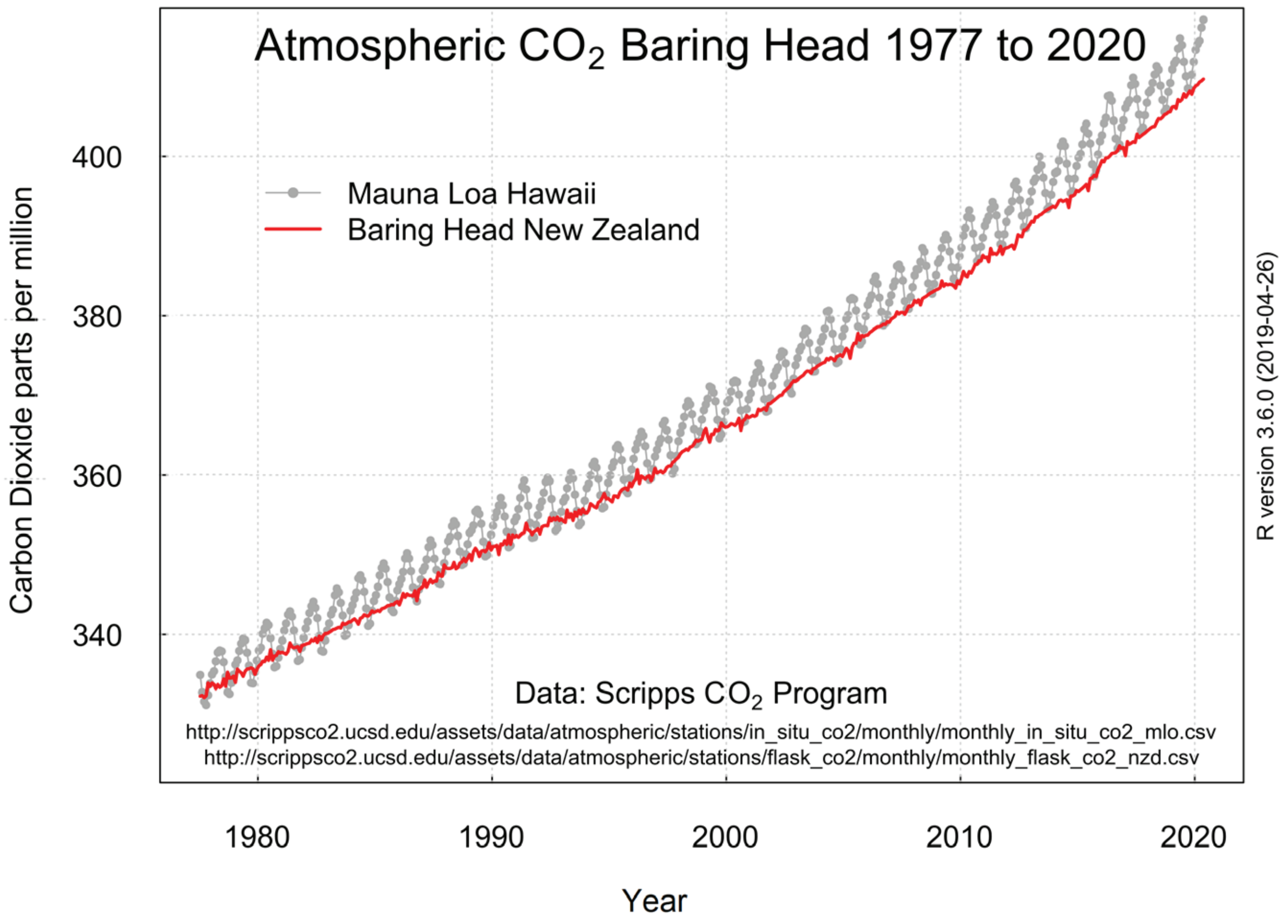
4. What gas was given off by the burning candle (combustion)? How can you tell?

a. Do you think burning other materials or objects gives off the same gas?

b. What is your evidence? Or, what evidence would you need to determine this?

Notes for the Facilitator: The solution should have turned green or yellow because the gas given off by the candle was mostly carbon dioxide, which lowers the pH when it interacts with water and forms an acid. The same thing occurs whenever anything containing carbon is burned, such as fossil fuels (oil, coal, gas).

5. **Data Analysis:** Examine the graph "Atmospheric CO_2 Baring Head 1977 to 2020". The graph shows carbon dioxide concentrations in the atmosphere at two locations. Describe and compare the trends shown.



Credit: Creative Commons, https://commons.wikimedia.org/wiki/File:Baringhead_co2_v9.svg

Notes for the Facilitator: Both locations show a steady increase in carbon dioxide. The Mauna Loa graph shows more fluctuation in carbon dioxide throughout the year by the peaks and valleys along the line, but there is still an overall increase from year to year. The fluctuations are seasonal and related to plant growth. The Baring Head data also has fluctuations, but they are about 5 times smaller than what is seen in the Mauna Loa data, and so are not obvious given the scale of the above graph. The smaller fluctuations in the Baring Head data are due to it being in the southern hemisphere, which has less change in CO_2 between seasons; this is thought to be due to there being more ocean in the southern hemisphere and the influence of the glaciated Antarctic landmass, while there is more land in the northern hemisphere (so more terrestrial plants, which cause fluctuations in CO_2 in the north). Since plants use carbon dioxide for photosynthesis, less carbon dioxide is used when there is not an active growing season, so there is a rise in carbon dioxide in the atmosphere. There is a small decline when plants are using more carbon dioxide for photosynthesis during a growing season. It may be helpful to show learners a graph of long-term change in atmospheric carbon dioxide so they can see the recent short rise: **https://bit.ly/carbondioxidechanges**.

6. **Data Analysis:** Examine the graph, "Carbon Sink Partitioning in Relation to Annual Carbon Dioxide Emissions".

   a. Describe the trend of annual carbon dioxide emissions line. What do you think is the most likely source of these emissions?

Notes for the Facilitator: Annual emissions are increasing every year. The rate at which they are going up also increases every year, which is shown by the line getting steeper. Answers may vary on the source of emissions, but burning fossil fuels and farming practices are the largest sources of greenhouse gas emissions.

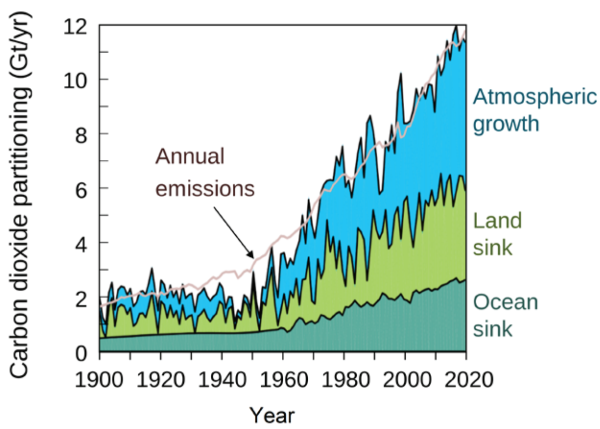
   b. Carbon dioxide is held in the atmosphere, geosphere (soil and rocks), and hydrosphere (bodies of water). Which of these spheres appears to be most affected by carbon dioxide emissions? Use evidence from the graph to support your ideas.

Notes for the Facilitator: The atmosphere, which can be seen as its section has increased the most out of the three sectors on the graph.

   c. Which sector shows the least variation in carbon levels over time? How do you know?

Notes for the Facilitator: Oceans have shown the least growth over time, but also, the line is flatter and more consistent, which means it varies little from year to year.

CARBON SINK PARTITIONING IN RELATION TO ANNUAL CARBON DIOXIDE EMISSIONS



Credit: Creative Commons, **https://commons.wikimedia.org/wiki/File:Carbon_Dioxide_Partitioning.svg**

7. **Data Analysis:** Examine the graph, "Atmospheric Carbon Dioxide Concentration and Global Temperature Trends," which shows changes in Earth's temperature alongside changes in atmospheric carbon dioxide in parts per million (ppm).

    a. How much has carbon dioxide increased between 1880 and 2009?

Notes for the Facilitator: Carbon dioxide has increased from about 290 ppm to 385 ppm. This is an increase of 95 ppm (about 33% — or a third) over 129 years.

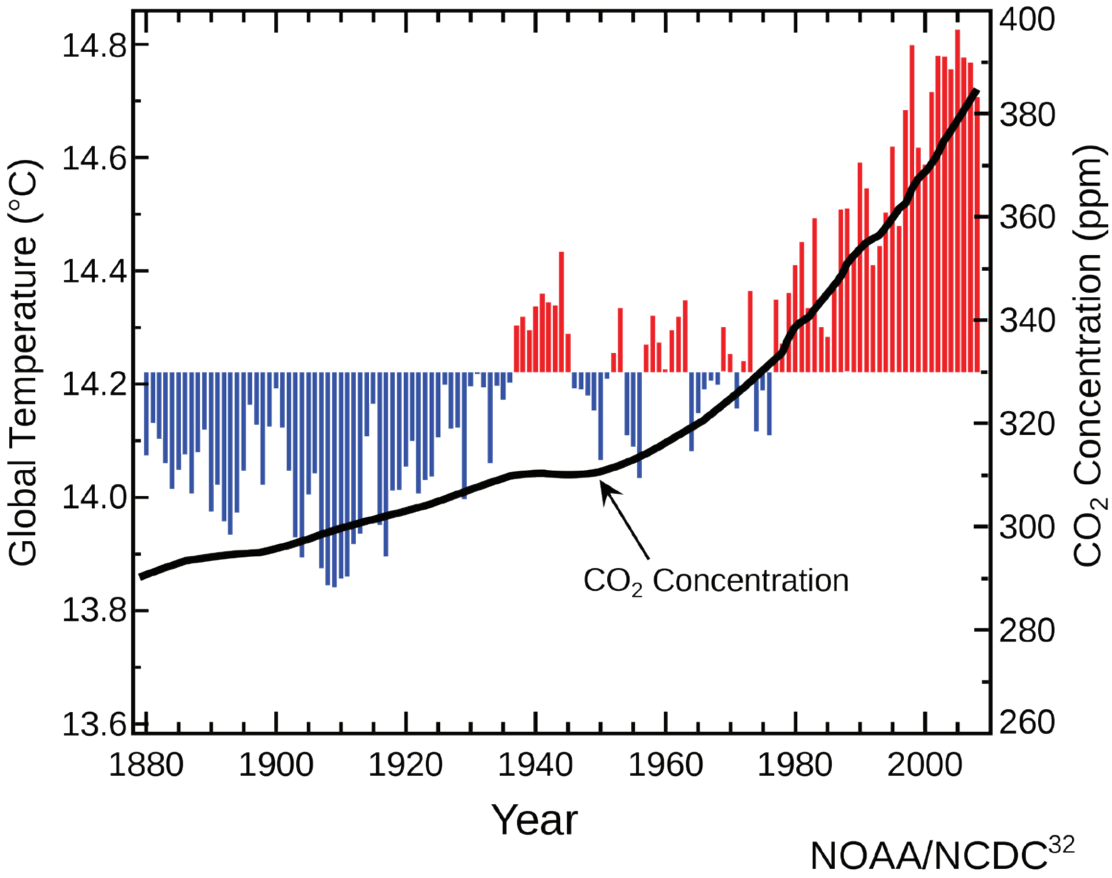
    b. The bars on the graph show the average yearly temperature. Describe the trend in global temperature over the time period shown. How does it compare with the trend in carbon dioxide concentration?

Notes for the Facilitator: The average global temperature decreased between 1880–1910. It then increased from 1910–1945. The temperature fluctuated up and down every few years between 1945–1978. 1978–2009 saw a rapid increase in average temperature. While there are exceptions, the overall trend shows an increase, which does follow the carbon dioxide concentration trend.

    c. Think about the models of oxygen and carbon dioxide you built and examined at the beginning of this Investigation. How do you think the structure of these molecules contributes to carbon dioxide's effect on global temperature? Do you think oxygen would have the same effect if its concentration increased? Why or why not?

Notes for the Facilitator: Carbon dioxide absorbs more energy from the sun than oxygen. It holds heat energy, which it then releases to the atmosphere, which then causes an increase in global temperature. Oxygen would not have the same effect because its bonds are not as flexible and cannot hold as much heat energy.

ATMOSPHERIC CARBON DIOXIDE CONCENTRATION AND GLOBAL TEMPERATURE TRENDS



Credit: Creative Commons, https://commons.wikimedia.org/wiki/File:Atmospheric_carbon_dioxide_concentrations_and_global_annual_average_temperatures_(in_C)_over_the_years_1880_to_2009.svg

Extensions

1. **Testing Variables:** Test respiration in different organisms:

   a. Mix 5 germinated beans (that have been soaked in water overnight) in 25 mL of water mixed with 5 drops of bromothymol blue. Observe the color change of the solution over a 15–30 minute period.

Notes for the Facilitator: The time it takes to change color can be sped up by using warm water.

   b. Mix 1 g of yeast with 25 mL of warm water and a pinch of sugar. Let sit for 10–15 minutes. Add 5 drops of bromothymol blue and observe the color change of the solution.

   c. Analyze your results:

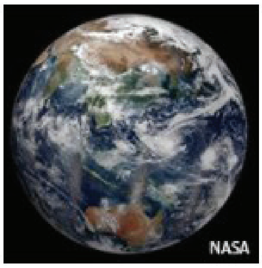
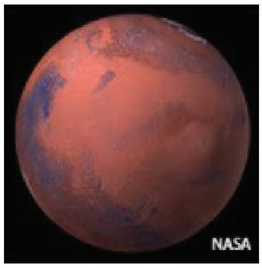
      i. What gases do these organisms give off? How can you tell?

      ii. How does this differ from a green plant?

      iii. Why is it that green plants can reduce the effects of climate change, while other organisms cannot?

Notes for the Facilitator: Beans and yeast give off carbon dioxide, which will be seen as the bromothymol blue solution they are in turns from blue to green or yellow. The yeast is digesting the sugar in the solution. Beans are digesting the sugars within them, but do not yet have green parts to do photosynthesis; while a green plant gives off carbon dioxide, they give off much more oxygen, so they would not cause nearly as much change in the color of the bromothymol blue. Green plants take in carbon dioxide from the atmosphere to do photosynthesis; a reduction in greenhouse gases will reduce the effects of climate change, or at least help prevent further change.

2. **Applying Concepts:** Compare the atmospheric gases of Earth to those of other planets. Use the data to make a representation of each atmosphere using pom poms. Based on the activity at: https://scied.ucar.edu/activity/learn/planetary-gases

			
	Venus	**Earth**	**Mars**
Carbon Dioxide (CO_2)	96.5%	0.03%	95%
Nitrogen (N_2)	3.5%	78%	2.7%
Oxygen (O_2)	Trace	21%	0.13%
Argon (Ar)	0.007%	0.9%	1.6%
Methane (CH_4)	0	0.002%	0

Credit: UCAR, https://scied.ucar.edu/activity/learn/planetary-gases

a. Label three clear plastic bags with the name of one of the planets. If your facilitator has already created a bag to represent Earth, you will only need two bags.

b. Choose a different color pom pom to represent each gas. Make sure the colors are consistent between each bag.

c. To determine how many pom poms of each color to put in each bag, read the percentages as regular numbers (round up for any decimal over .5). For example, the bag for Venus will have 97 carbon dioxide pom poms, Earth will have a small piece of one carbon dioxide pom pom, and Mars will have 95 carbon dioxide pom poms.

3. Describe the similarities and differences in the atmospheric gases of the three planets.

    a. Which planets have similar atmospheres?

    b. Which planet has the highest concentration of greenhouse gases? What effect would you expect this to have on the average temperature of the planet?

    c. Venus' atmosphere is very dense, while Mars' atmosphere is very thin. This means that there are fewer molecules of each gas type in Mars' atmosphere when compared to Venus. What effect do you think this has on Mars' average temperature?

    d. If possible, research the average temperatures or temperature ranges of each of these planets and use the information you have been given to explain their differences.

Notes for the Facilitator: Venus and Mars have similar atmospheres comprised mostly of carbon dioxide, which is a greenhouse gas. Venus has the greatest percentage of carbon dioxide, so one could predict it to have the highest temperature, which is also consistent with the information in question c. A denser atmosphere is typically warmer than a thinner one. Mars might have a high percentage of carbon dioxide, but since its atmosphere contains fewer gas molecules, it would not hold as much heat as Venus' atmosphere. Earth has much less carbon dioxide, but does have some methane, which is also a greenhouse gas. The greenhouse effect on Earth helps sustain life by keeping the global temperature between −89 °C (−129 °F) and 58 °C (136 °F). The temperature on Venus typically stays around 465 °C (870 °F), while Mars ranges from −125 °C (−195 °F) to 20 °C (70 °F). (Data source: **http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_planet_temp.html**). These temperature ranges are expected given the levels of greenhouse gases and the relative thickness of each planet's atmosphere; but these factors only help a planet's atmosphere hold heat. Distance from the sun also helps Venus to be much warmer than Earth, and Earth to be somewhat warmer than Mars.

ESD KIT:
IMPACTS OF CLIMATE CHANGE

Sustainable Development Goal 13: Climate Action

INVESTIGATION 3A:
MEASURING CARBON DIOXIDE AND ACIDITY

Facilitator Background

Connection to SDG 13: Indicator 13.2.2 states that countries will integrate climate change measures to reduce "total greenhouse gas emissions per year" (**https://sdgs.un.org/goals/goal13**). Greenhouse gases are gases that lead to increased atmospheric heating. They include carbon dioxide, methane, and nitrous oxide, among others. These gases occur naturally, but the combustion of fossil fuels has led to an unnatural increase in their concentrations in the atmosphere. These gases can mix with water in the atmosphere, which can lead to the production of acid rain. That is, rain that has a lower pH than normal rain. In this Investigation, learners will come to understand acid rain as a climate-related hazard by exploring how fossil fuel emissions relate to the production of acid rain as well as how acids affect bodies of water, living organisms, and infrastructure.

Key Concepts: *climate-related hazard, greenhouse gas*

Learning Outcome: Conduct tests to determine the effects of carbon dioxide on the pH of water and the effects of acids on other materials.

Connect to the ESD Kit Project: Design a Resilient City: Understanding how acid rain affects living organisms and human-made structures can inform learners on now to design a city that is less likely to be affected by acid rain than other cities.

PACING GUIDE

PREPARATION

20 minutes setting up materials for groups

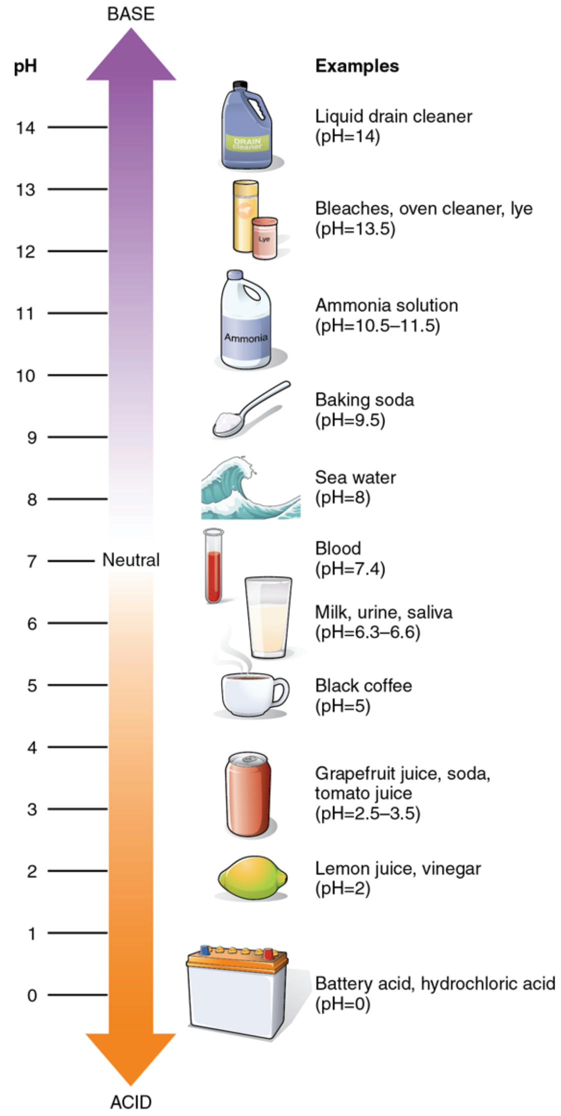
WHAT TO DO

5 minutes discussing the introduction material

20 minutes for each station of the Investigation

Introduction

Acids are substances that have a low pH. A neutral substance has a pH of 7. Bases are substances that have a high pH. Examples are shown on the pH scale below. Both strong acids and bases have negative effects on other objects and can break them down or dissolve them. Some gases in the atmosphere mix with water to create acid rain, which affects the environment.



Credit: Mangalassery, S., Sjögersten, S., Sparkes, D. *et al*. To what extent can zero tillage lead to a reduction in greenhouse gas emissions from temperate soils?. *Sci Rep* **4**, 4586 (2014). https://doi.org/10.1038/srep04586

Notes for the Facilitator: There are four procedures (Groups) in this Investigation. These can be done as stations, or different groups can complete one of the procedures and share their results with other groups. The four procedures are written in an order where they build on each other, so if groups share out, have group 1 share first and discuss the results by making connections between the procedures. If learners complete the procedures as stations, they can go in any order, but when discussing results, conduct the discussion by attending to the stations in numerical order.

GROUP A:
FORMING ACID RAIN

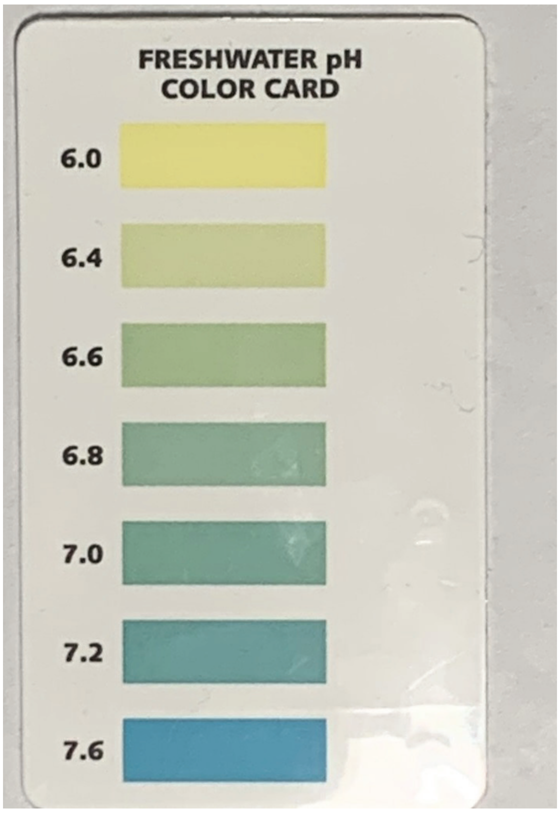
Materials

Per group:

- 2 small cups
- water
- small cup of apple cider or white vinegar
- pH paper
- petri dish or similar clear, shallow dish with a cover
- 2 pipettes or medicine droppers
- toothpick
- bromothymol blue (or other pH indicator solution)
- stopwatch or clock with a second hand
- camera (optional)

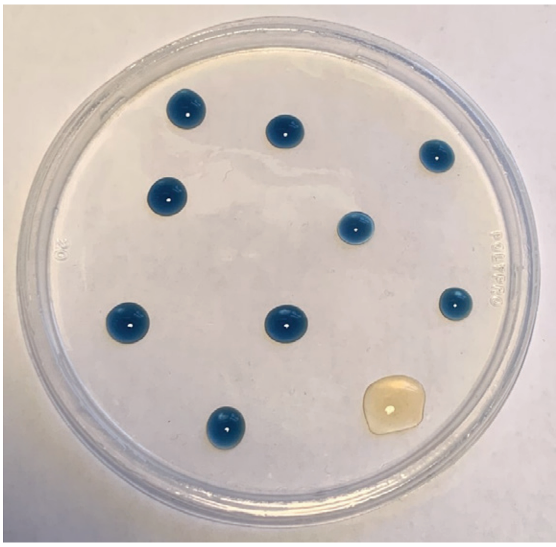
What to Do

1. Use a small strip of pH paper to measure the pH of the vinegar. Use another strip to measure the pH of the water.
2. Add enough water to a small cup to fill a pipette (approximately 3 mL). Add 8–10 drops of bromothymol blue until the solution is an even blue color. Fill a pipette with this solution.
3. Use the pipette full of solution to make 6–10 drops in different areas of a petri dish. Each drop should contain 2–3 droplets of solution.
   a. Record the initial color of the drops.
   b. Compare this to the color chart that comes with the indicator. What is the pH of the drops?



Credit: L.C.Mossa

4. Use a new pipette to add 5 drops of vinegar to the petri dish. Add the vinegar along the side of the dish or in another spot where it will not come into contact with the water drops.



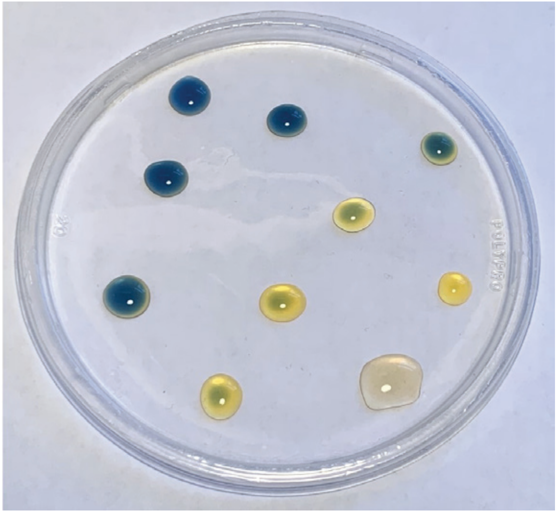
Credit: L.C.Mossa

5. Cover the dish. Wait one minute to observe the color of each water drop. Record the color every minute for 15 minutes.
    a. Be careful not to bump or move the dish.
    b. If possible, take pictures of the color changes.
6. After the 15 minutes of observation, add three drops of bromothymol blue to the vinegar spot in the petri dish to test its pH.

Consider

1. Compare the rate of color change in the different drops of water.

Notes for the Facilitator: Learners should observe more color change in the drops closer to the vinegar. More change in the same amount of time means the rate of color change in the closer drop is faster. The image below shows the results after 15 minutes. Both drops started blue (pH around 7.6). After 15 minutes, the water drop that is closer to the vinegar is almost completely yellow (pH around 6), and the drop farther away is mostly green (pH around 7).



Credit: L.C.Mossa

2. Describe how you think the water became more acidic (a lower pH) over time. Remember, the vinegar never touched the water drops.

Notes for the Facilitator: Vinegar is acidic and can evaporate. The vapor travels through the air (much like rainwater), and when it comes into contact with the water droplets, it mixes with the water and causes the pH to drop. The indicator in the water droplet then changes color due to the change in pH.

3. When carbon dioxide mixes with water, it produces carbonic acid. Describe how an increase in atmospheric carbon dioxide can lead to acid rain.

Notes for the Facilitator: The carbon dioxide can dissolve in water in the atmosphere which creates carbonic acid. This acidic water forms clouds and then is released during precipitation events. The acid in vinegar is acetic acid, which is not the same as carbonic acid. The Investigation demonstrates that acid can travel through the air and mix with water in the air or on the surface.

Extension

1. **Analyzing Data:** Examine the map "Potential Effects of Acid Rain". The yellow areas on the map are where emissions that can lead to acid rain are occurring. The red areas are the regions where acid rain is already causing problems in the environment.

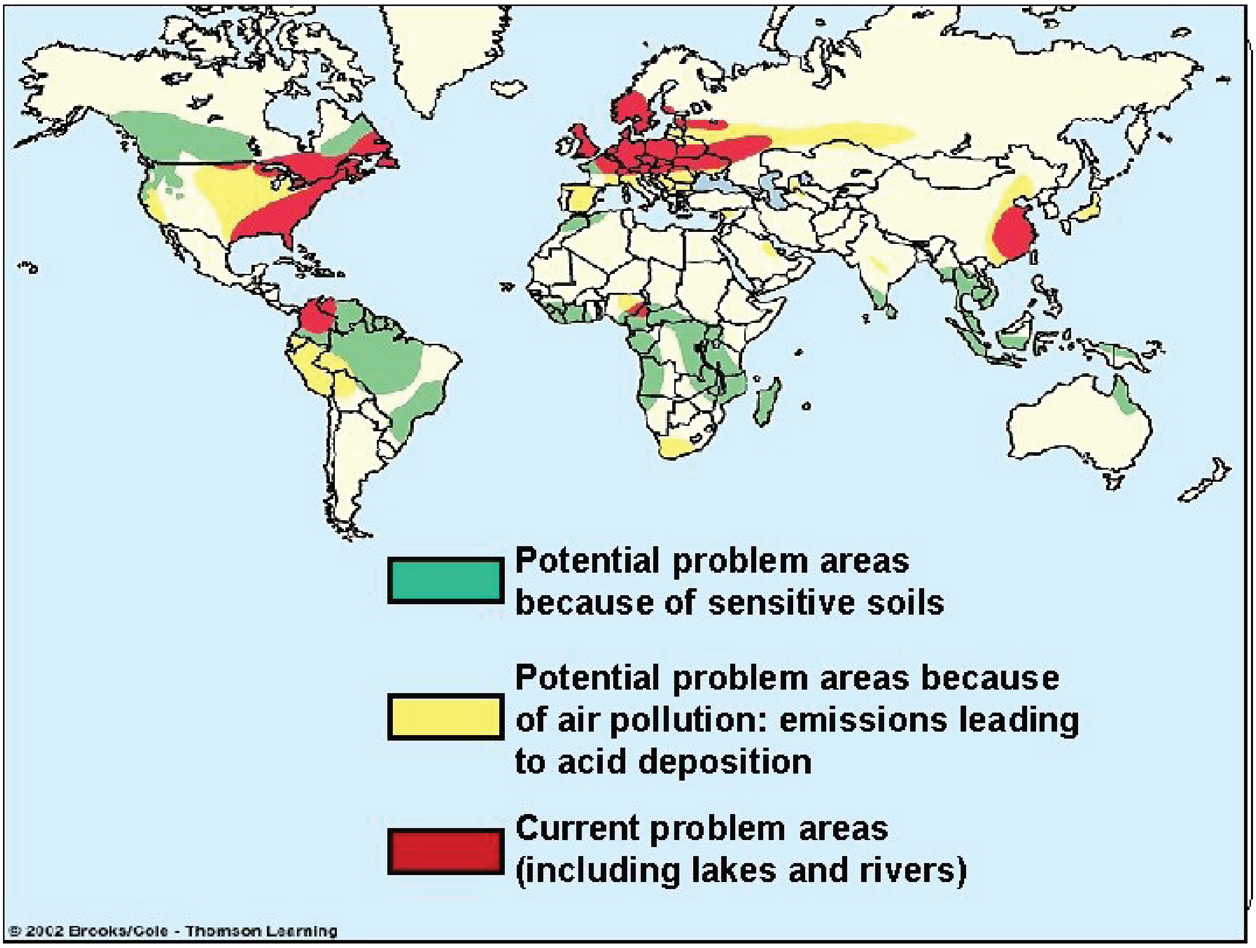
   a. Describe the patterns with the yellow and red areas on the map.

   b. Why do you think the areas that produce emissions that cause acid rain are not the same areas that get acid rain?

   c. Are there any locations on the map that don't follow the pattern(s)? Why do you think that is?

Notes for the Facilitator: Yellow regions, where acid rain is most commonly being produced due to pollution, tend to be right next to red areas, which are the areas getting the most acid rain. Wind patterns cause this, because rain rarely falls right where it is made. Wind moves the rain clouds, and since global winds tend to follow trends, clouds with acid rain are moved to the same areas each time. The only place we do not see this pattern (of yellow being nearby red) is in South Africa, where the acid rain likely falls over the ocean and is not monitored.

POTENTIAL EFFECTS OF ACID RAIN



Credit: Brooks and Cole, Thomson Learning

GROUP B:
CARBON DIOXIDE AND pH

Materials

Per group:

- water (tap or distilled)
- salt water (7 g salt per 200 mL water)
- straw
- 2 small plastic cups (less than 240 mL [8 oz])
- bromothymol blue (available in many aquarium water test kits)

What to Do

Notes to the Facilitator: Carefully review the following procedure and consider whether it would be appropriate for learners to conduct given possible safety concerns. Demonstrating for learners how to safely exhale into the bromothymol solution before they conduct it may help. The procedure could also be done as a demonstration.

1. Fill one cup halfway with cold water.
    a. Add 12 drops of bromothymol blue. Gently stir using the straw until the color is evenly distributed. Record this initial color. Examine the pH color chart that came with the indicator and record the pH of the water.
2. When you inhale, what gases do you breathe in? When you exhale, what gases do you breathe out?
3. Predict what will happen to the pH of the water when you exhale into it. Explain why you think so.
4. Use the straw to very gently blow bubbles (exhale) into the water in the cup. Start a timer when you start blowing bubbles and keep it running. Note the time when the solution turns green, and again when it turns yellow. Stop when the solution is yellow.

Caution: *Remove the straw from your mouth while inhaling, so you do not ingest the bromothymol blue. Pause the timer whenever you stop to inhale.*

    a. Keep your bubbles and the liquid in the cup. Be sure not to exhale too hard that causes the cup to overflow.
5. Note any color changes that occur in the cup.
6. Make a prediction as to what will happen with each of the following setups. Will the temperature and salt content of the water affect how long it takes to change pH (color)? Repeat this procedure with each setup:
    a. Warm fresh water
    b. Cold salt water
    c. Warm salt water

Notes for the Facilitator: Different groups of learners could test fresh or salt water and compare their results.

Consider

1. One of the gases you exhale is carbon dioxide. What effect did it have on the pH of the water?

a. Compare the pH test results between freshwater and saltwater over time.

b. Compare the pH test results between colder and warmer water over time.

Notes for the Facilitator: The freshwater should take significantly shorter time to change color than the saltwater. Carbon dioxide is more easily dissolved in freshwater compared to saltwater. Therefore, saltwater will show less rapid change in pH than fresh water. Warmer water will become more acidic than colder water. Colder water is more resistant to a change in pH than warm water.

2. Consider carbon dioxide and bodies of water, such as lakes, rivers, and oceans.

   a. How might carbon dioxide get into bodies of water? Where does it come from?

Notes for the Facilitator: Carbon dioxide can diffuse and dissolve directly into water from the atmosphere. Also, organisms that live in the water give off carbon dioxide into the water.

   b. Can carbon dioxide also leave bodies of water? If not, explain why. If yes, describe where it goes.

Notes for the Facilitator: Yes, carbon dioxide can diffuse out of water and back into the atmosphere. Also, aquatic plants take in carbon dioxide that is dissolved in the water for photosynthesis.

3. The amount of atmospheric carbon dioxide is increasing. Describe what effect this will have on the pH of rain and bodies of water.

Notes for the Facilitator: The more carbon dioxide mixes with water, the more acidic both rain and bodies of water will become.

Extensions

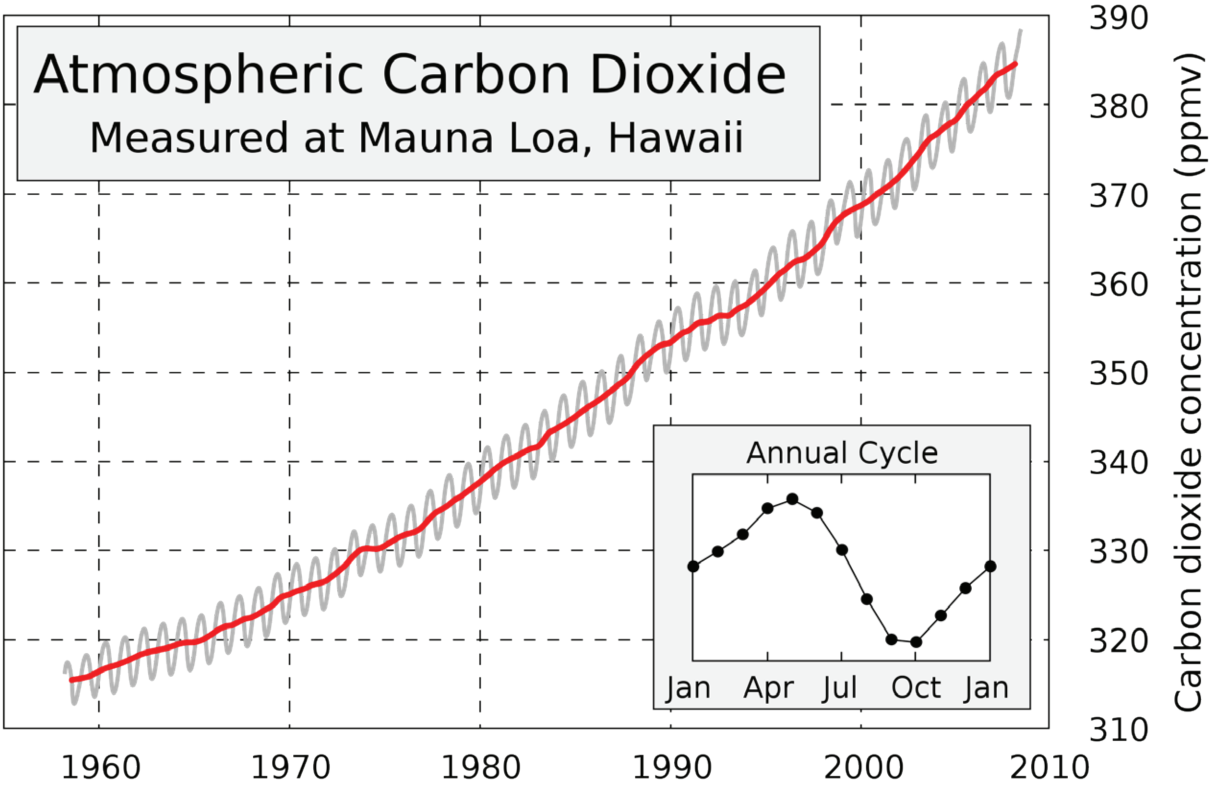
1. **Analyzing Data:** Examine the graph, “Atmospheric Carbon Dioxide”. It shows atmospheric carbon dioxide levels between 1958 and 2008. The grey line is of the actual data, while the red line is the average trend.

   a. Describe the annual cycle of atmospheric carbon dioxide (grey line and inset).

   b. Describe the trend of the graph (red line).

   c. Predict the likely effect of this trend on the pH of oceans.

Notes for the Facilitator: The grey line and inset show how carbon dioxide levels fluctuate each year. Carbon dioxide builds up between November and May, when there is not an active growing season for plants. Carbon dioxide levels dip during growing seasons (June to October), when plants take in carbon dioxide to do photosynthesis. Carbon dioxide increased from about 316 ppmv (parts per million volume) in 1958 to approximately 385 ppmv in 2008. The line is not perfectly straight, indicating there are some years carbon dioxide levels increased more than in other years, for example 1973–1974 had a slightly sharper increase. More carbon dioxide in the atmosphere leads to more carbon dioxide transferring into bodies of water. Carbon dioxide mixes with the water and forms carbonic acid, which causes the pH of the water to decrease (become more acidic).



Credit: Robert A. Rohde, https://commons.wikimedia.org/wiki/File:Mauna_Loa_Carbon_Dioxide-en.svg

GROUP C:
TEMPERATURE AND DISSOLVED CARBON DIOXIDE

Materials

For the Facilitator:

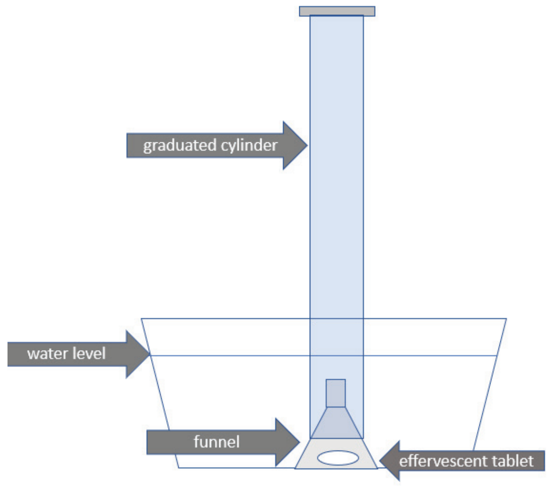
- thermometer

Per group:

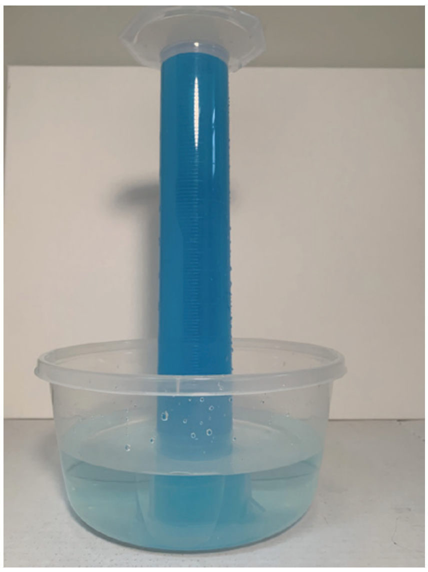
- 500 mL graduated cylinder or clear water bottle
- plastic funnel with a short stem
- plastic bin or bowl (10–15 cm [4–6 in] deep)
- cold water (approximately 10°C [50°F])
- warm water (approximately 20°C [68°F])
- hot water (approximately 30°C [86°F])
- sodium bicarbonate tablets (effervescent antacids, such as Alka-Seltzer®)
- tape
- food coloring (optional)

What to Do

1. Place the funnel near the center of the bin so that the smaller opening is turned upward.
2. Fill the bin about halfway with cold water. The funnel should be fully submerged. If not, add more water.
3. Fill the graduated cylinder all the way with cold water. Add 5–10 drops of food coloring if you have it.
4. Place your hand over the top of the graduated cylinder and quickly invert it so that your hand and the top of the cylinder are in the bin of water.
5. There can be a small air bubble in the graduated cylinder, but it is ideal if there is no air. If some air does get inside, use tape to mark where it is on the cylinder.



Credit: E.C.Robeck



Credit: L.C.Mossa

6. Keeping the cylinder underwater, move it so it is on top of the funnel. Hold the cylinder to keep it from falling over.

7. Carefully tilt the graduated cylinder and funnel and place an effervescent tablet under the funnel. Quickly stand the funnel and graduated cylinder up straight to trap the gas coming from the tablet.

8. Take observations of what you see happening.

9. Once the tablet has completely dissolved, measure the gas pocket that has formed in the top of the cylinder. Also note how much the water in the bowl has changed color, if you used food coloring.

Notes for the Facilitator: The image shows the results for cold water. The air space at the top of the graduated cylinder can be measured in mL or cm. Ensure that all learners are using the same units. Note that there is more blue coloring in the bowl than at the start of the experiment due to displacement of the water in the graduated cylinder by carbon dioxide entering the cylinder.

Credit: L.C.Mossa

10. Predict what would happen if you used warmer water. Repeat the procedure with warm water, and then with hot water.

Notes for the Facilitator: Different groups of learners could test hot, warm, or cold water and compare their results.

Consider

1. Compare the results from the different water temperatures. The effervescent tablet released carbon dioxide. Each of the tablets started the same size, so how can you explain any differences that occurred with the different temperatures of water?

Notes for the Facilitator: The warmer the water, the larger the air pocket. Carbon dioxide dissolves more readily in cold water, so there was less carbon dioxide gas released into the graduated cylinder. Warmer water does not hold as much dissolved carbon dioxide, so more gas accumulates in the graduated cylinder rather than dissolving in the water.

2. Oceans are considered carbon sinks, which means that they hold a large amount of carbon in the form of dissolved carbon dioxide.

   a. Describe how an increase in water temperature would affect the ability of the oceans to act as a carbon sink.

   b. What effect would this have on the atmosphere and air temperatures? Explain.

Notes for the Facilitator: Since warmer water cannot hold as much carbon dioxide, warmer oceans would have less of an ability to act as a carbon sink and would release carbon dioxide into the atmosphere. Since carbon dioxide is a greenhouse gas, a higher concentration of it in the atmosphere would contribute to even more warming.

Extensions

1. **Testing Variables:** Predict how your results would differ if you tested saltwater instead of freshwater. If there is time, test your prediction (35 g of salt per 1000 mL of water would be similar to ocean water).

Notes for the Facilitator: Saltwater should have a larger pocket of air in the graduated cylinder than freshwater, since freshwater can hold more dissolved carbon dioxide.

2. **Testing Variables:** Predict what would happen if you used more than one tablet at a time. If there Is time, test your prediction.

Notes for the Facilitator: A larger pocket of air should form in the test tube with more tablets. There is a limit to how much carbon dioxide the water can hold, so no matter how many tablets are used, no more carbon dioxide will go into the water, but will end up in the test tube instead.

3. **Analyzing Data:** Examine the world map "Sea Temperature Readings".

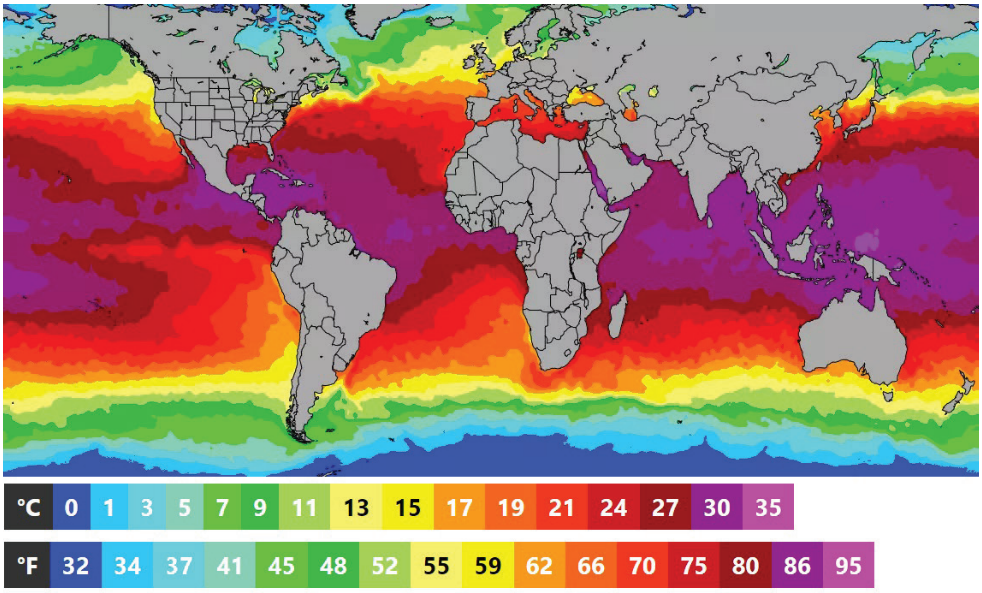
    a. Describe any patterns you observe in sea temperatures.

    b. Where would you expect there to be the highest levels of dissolved carbon dioxide?

    c. Would you expect the pH of these areas to be higher or lower than areas with less dissolved carbon dioxide? Explain.

Notes for the Facilitator: Each color makes a horizontal band across the oceans. The highest temperatures are near the equator. Temperature decreases as you move away from the equator in either direction. There are larger blue regions in the South Pole than in the North Pole, indicating the waters in the South Pole are colder on average. Since warmer waters cannot hold as much dissolved carbon dioxide as colder water, there is likely to be more carbon dioxide dissolved in water near the poles. Areas with less carbon dioxide should have a higher pH (be less acidic) than water with more carbon dioxide, so the highest pHs should be where there are also higher temperatures.

SEA TEMPERATURE READINGS



Credit: https://www.seatemperature.org/

Notes for the Facilitator: The map was compiled on the 3rd of January 2022, but is updated daily at: **https://www.seatemperature.org/**. Visit the link if you want to use a more recent version, or if you want a second map for comparison.

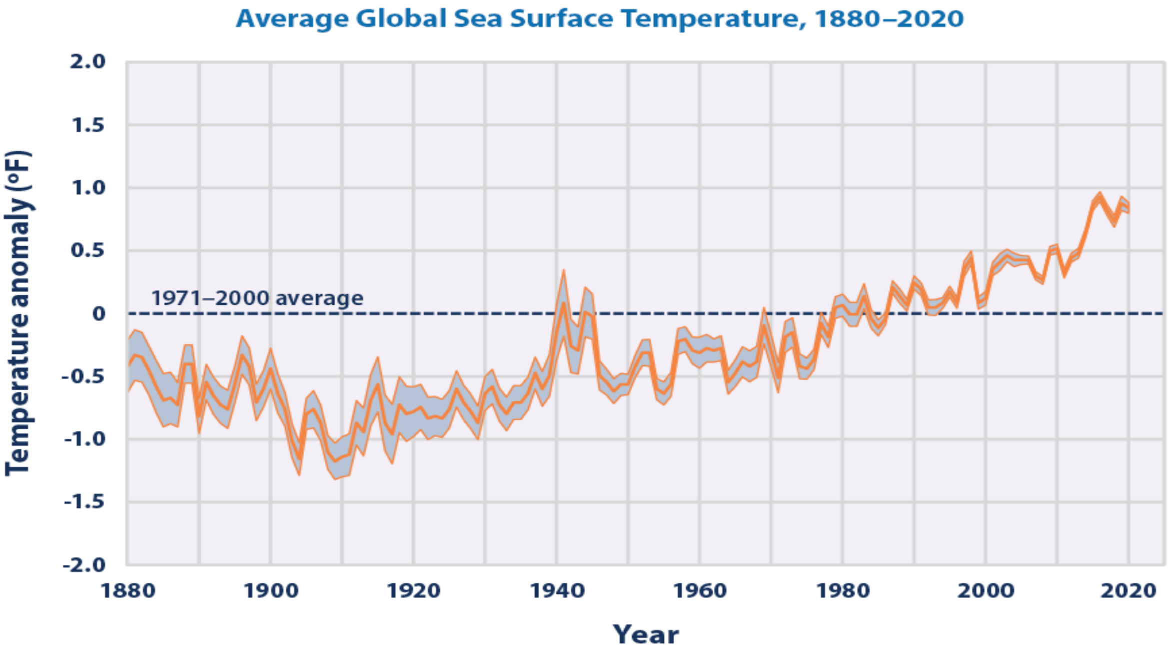
4. Examine the graph, “Average Global Sea Surface Temperature, 1880–2020”. The average was taken by using values from 1971 to 2000, and the graph shows any differences between this average (set at 0) and the average global sea temperatures each year.

a. Describe the trend of the graph.

b. Predict the effect of this trend on the amount of dissolved carbon dioxide in the surface water of oceans.

c. Predict the effect of this trend on the pH of surface water in oceans.

Notes for the Facilitator: Global sea surface temperatures were below the calculated average between 1880 and 1940 and again between 1945 and 1978. All other years had temperatures above average, and the overall trend shows an increase in global sea surface temperatures. Warmer water cannot hold as much dissolved carbon dioxide, so it would escape from the surface waters to the atmosphere more readily. Less carbon dioxide in the surface waters would cause them to have a higher pH.



Data source: NOAA (National Oceanic and Atmospheric Administration). 2021. Extended reconstructed sea surface temperature (ERSST.v5). Accessed February 2021. www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Credit: EPA, Data Source: NOAA

GROUP D:
EFFECTS OF pH

Materials

Per group:

- apple cider or white vinegar
- pipette or medicine dropper
- chalk (cannot be dustless chalk or molded chalk)
- mortar and pestle (or another tool that can safely crush the chalk)
- petri dish or plastic food container
- jars containing vinegar and an item (eggshell, leaves, paper clips, apple slice, etc.)

Notes for the Facilitator: Since these jars are for observation, groups can share them. The jars need to be set up at least one day before learners are to make observations on them, though 2–4 days is recommended. It is also an option to have some jars that have been sitting for many days in addition to ones that have been sitting overnight, to compare changes over time. It is also suggested to have jars containing the same items in water as a control.

What to Do

1. Test the pH of the vinegar.
2. Place a small piece of chalk into a petri dish.
3. Using a pipette, put 5 drops of vinegar on the chalk. Record your observations for one minute.
4. Add 5 more drops of vinegar to the chalk and make observations for one more minute.
5. After the minute, take the pH of the vinegar that has reacted with the chalk.
6. Rinse and dry the petri dish.
7. Crush a piece of chalk into a powder and place it in the petri dish.
8. Using a pipette, put 5 drops of vinegar on the chalk. Record your observations for one minute.
9. Add 5 more drops of vinegar to the chalk and make observations for one more minute.
10. After the minute, take the pH of the vinegar that has reacted with the chalk.
11. Observe the items that have been left in jars of vinegar. Record observations, noting how long the items have been sitting in the vinegar.

Notes for the Facilitator: Once all groups have taken observations, it is suggested you remove the items from the vinegar so learners can see changes in texture. If you only have one jar set up for each item, this can be done as a demonstration; if you have multiple jars, learners can do this in their groups.

Consider

1. Compare your observations from the experiment using a piece of chalk and crushed chalk. Describe differences between your results.

Notes for the Facilitator: The piece of chalk fizzed when it came into contact with the acid (vinegar). The crushed chalk fizzed more because of a greater surface area for the chalk to be able to contact and react with the vinegar. The fizzing was evidence that the chalk was reacting with the vinegar. The crushed chalk dissolved faster than the whole piece of chalk. The pH of the vinegar may increase as the acid is used up in the reaction. Crushed chalk should result in a greater pH change due to a greater amount or rate of reaction.

2. Coral and shelled marine animals build their shells using calcium carbonate that is dissolved in seawater.

   a. Calcium carbonate is the same molecule that makes up chalk. Use this information to predict how oceans becoming more acidic will affect coral and shelled marine animals.

Notes for the Facilitator: Acids can dissolve calcium carbonate, so more acidic water may wear away the shells of these marine organisms.

   b. More acidic water is able to hold less dissolved calcium carbonate. How do you think oceans becoming more acidic will affect the growth of shelled organisms?

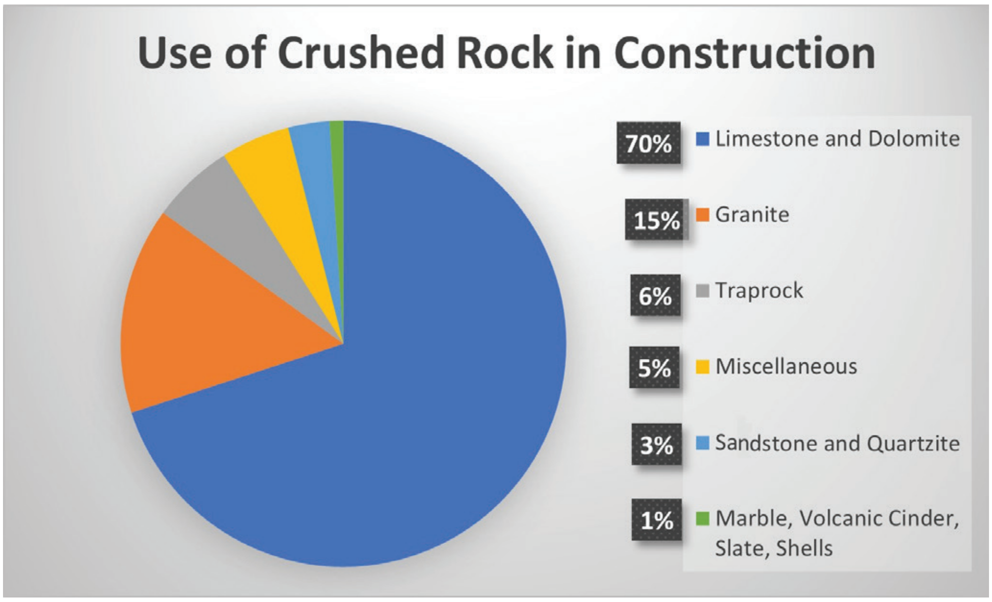
Notes for the Facilitator: More acidic water holds less calcium carbonate, so it is not accessible to shelled organisms. These animals would not be able to grow very well, since they would not have enough calcium carbonate to build larger shells or repair the damage done by acids eroding their shells.

3. Rank the items soaked in vinegar from most to least affected. Describe what evidence you used to put the items in the order you did.

Notes for the Facilitator: Answers will vary based on what items are used. Look for color and texture changes to indicate that the vinegar had an effect on each item.

Extension

1. **Analyzing Data:** Examine the graph, "Use of Crushed Rock in Construction". It shows the use of different types of rocks in construction materials for roads and buildings. Limestone and Dolomite are made of calcium carbonate. How do you think acid rain affects buildings and roads?



Credit: L.C.Mossa, Produced from data from USGS, 2020, https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-stone-crushed.pdf

Notes for the Facilitator: Since limestone and dolomite are made of calcium carbonate, acid rain can erode them. They are commonly used in construction materials, so acid rain can wear away the exterior of buildings over time that are produced using these crushed rocks. Acid rain can also impact parts of other rock types as well, because calcium carbonate can also be the cement that holds some sandstones together; marble is metamorphosed limestone; and certain minerals in granite are also susceptible to acids.

SUSTAINABLE DEVELOPMENT GOALS

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connecting earth, science, and people

INVESTIGATION 3B: ANALYZING GREENHOUSE GAS EMISSIONS

Facilitator Background

Connection to SDG 13: Indicator 13.2.2 states that "[countries will integrate climate change measures to reduce] total greenhouse gas emissions per year" (**https://sdgs.un.org/goals/goal13**). Greenhouse gas emissions lead to the production of acid rain, which then leads to more acidic bodies of water. Ocean acidification is due to increased levels of carbon dioxide moving from the atmosphere to the oceans and mixing with ocean water to form carbonic acid. Unlike other climate-related hazards, acidic water is not something that can be combated with adaptation strategies. Mitigation in the form of reducing greenhouse gas emissions and preventing further acidification of water is the necessary strategy for impact reduction when it comes to acid rain, which is examined in this Investigation

Key Concepts: climate-related hazards, impact reduction, mitigation

Learning Outcome: Analyze data to explain greenhouse gas emissions and the major contributors to their accumulation in the atmosphere.

Connect to the ESD Kit Project: Design a Resilient City: Learners can integrate clean, renewable energy sources into their city to reduce greenhouse gas emissions, which will then reduce the production of acid rain.

PACING GUIDE

PREPARATION
10 minutes making copies of graphs

WHAT TO DO
30 minutes for the Investigation

Materials

Per group:

- copies of graphs within the Investigation

What to Do

1. Examine the graph "Greenhouse gas emissions by sector, World".

Notes for the Facilitator: Information on how different sectors produce these emissions can be found here: https://www.epa.gov/ghgemissions/overview-greenhouse-gases. This resource is specific to the United States, but many of the examples are consistent with the source of emissions in other countries.

a. Which two sectors had the greatest increases in emissions from 1990 to 2016? Why do you think this is?

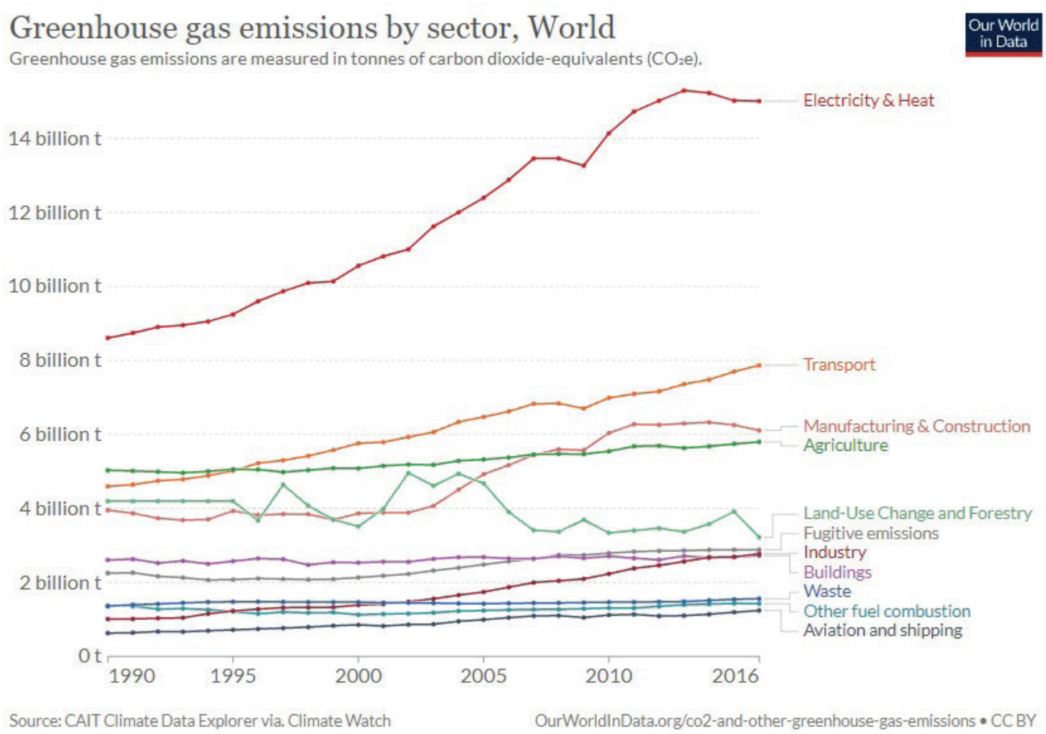
Notes for the Facilitator: Electricity & Heat, and Transport increased the most. Answers about why will vary, but could include: As the world population increases, there is a greater demand for both electricity and transport (cars, buses, planes, etc.).

b. Which sectors decreased in emissions from 1990 to 2016? Why do you think this is?

Notes for the Facilitator: Land-Use Change and Forestry, and Buildings decreased.

c. Do you think all countries contribute equally to greenhouse gas emissions? Why or why not?

Notes for the Facilitator: No. Answers may vary, but could include: emissions per country are related to population size; laws and regulations imposed by certain countries may limit fossil fuel use regardless of population size; many countries use alternative, renewable energy sources, which leads to them using less fossil fuels and creating fewer emissions.



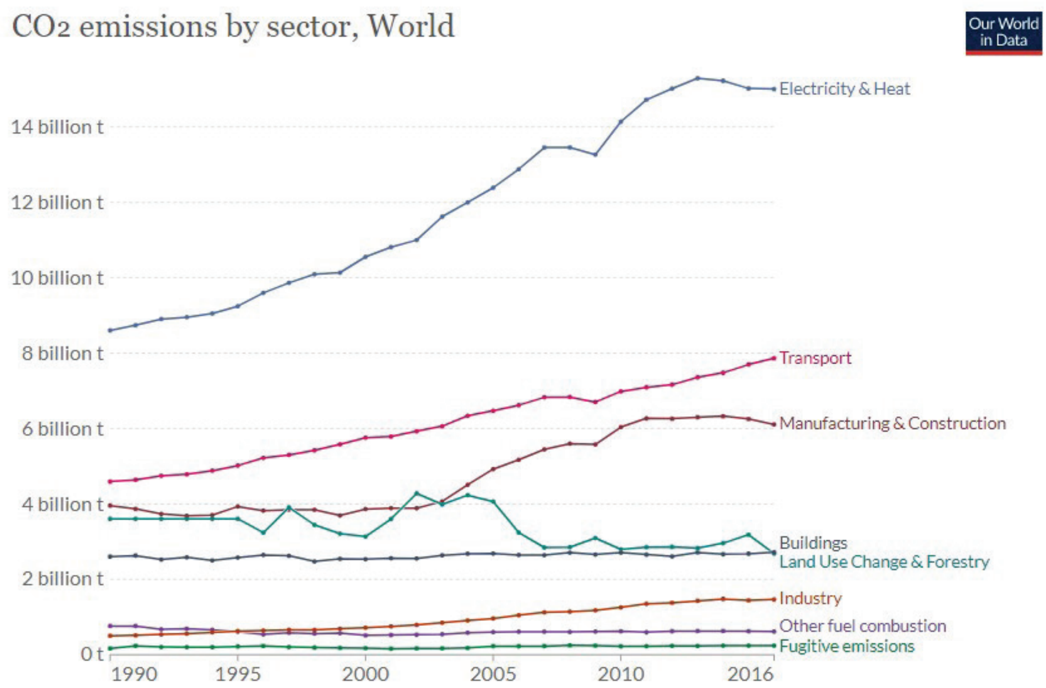
Credit: Our World In Data, https://ourworldindata.org/emissions-by-sector

Notes for the Facilitator: Each of these graphs from Our World In Data are available in interactive form on their site: https://ourworldindata.org/emissions-by-sector A breakdown of each country's contribution is also available, in both graph and data formats.

2. Examine the graph, “CO_2 emissions by sector, World”. This graph looks only at carbon dioxide emissions.

   a. Compare the trends on this graph to the trends on the total emissions graph. Describe some similarities and differences. Why do you think there are differences?

Notes for the Facilitator: All of the lines except Fugitive Emissions (leaks from pipes or storage tanks) have the same overall trend as the total greenhouse gas graph, as well as the same relative contributions; for example, Electricity & Heat having the largest increase and the largest emissions reading. Differences exist because while some industries give off greenhouse gases, they might give off something other than carbon dioxide. Agriculture; Aviation and Shipping; and Waste are not on this graph (they may be part of the other group, but there is no reference to them). Fugitive Emissions has the same trend (flat line). However, the relative contribution of carbon dioxide is much lower than total emissions.

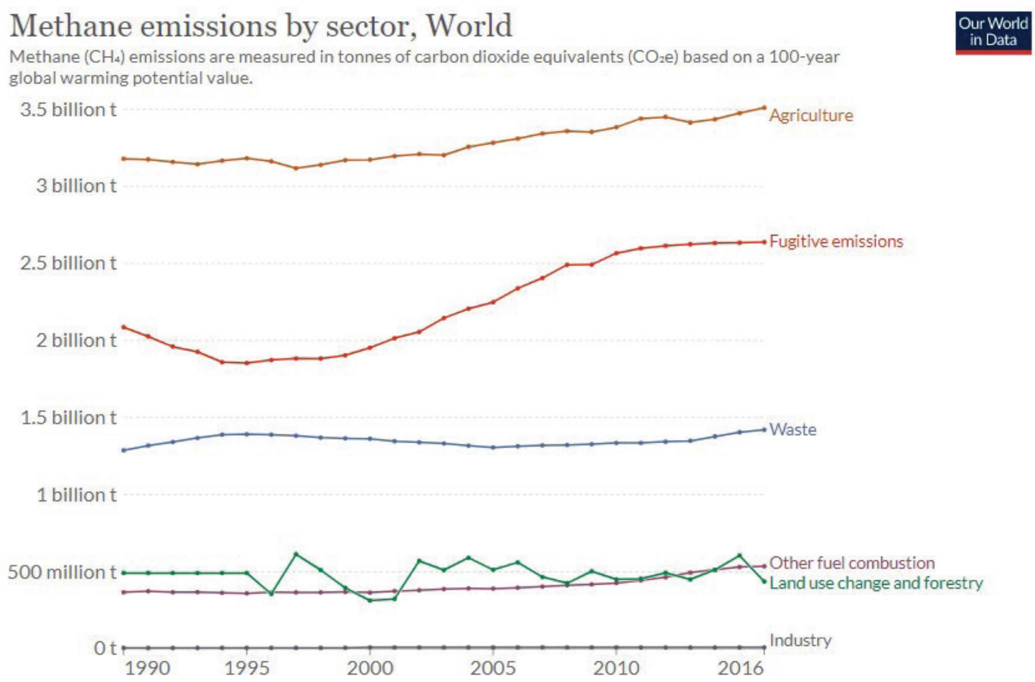


Credit: Our World In Data, **https://ourworldindata.org/emissions-by-sector**

3. Examine the graph, “Methane emissions by sector, World”.

   a. Compare the trends on this graph to the trends on the total emissions graph. Describe some similarities and differences. Why do you think there are differences?

Notes for the Facilitator: The lines for Agriculture, Waste, and Industry have similar slopes as the graph of total emissions. These sectors have different relative contributions, however, with Agriculture and Waste having much larger methane contributions, while Industry has a much smaller methane contribution. Fugitive Emissions has a different trend line for methane than the total emissions, as well as a much higher contribution of methane. Land use has a more stable methane trend (rather than decreasing) and has a lower contribution of methane than total emissions . All of the other categories are not contributors to methane emissions or are included in the Other category; these other sectors produce greenhouse gases other than methane.



Credit: Our World In Data, https://ourworldindata.org/emissions-by-sector

Consider

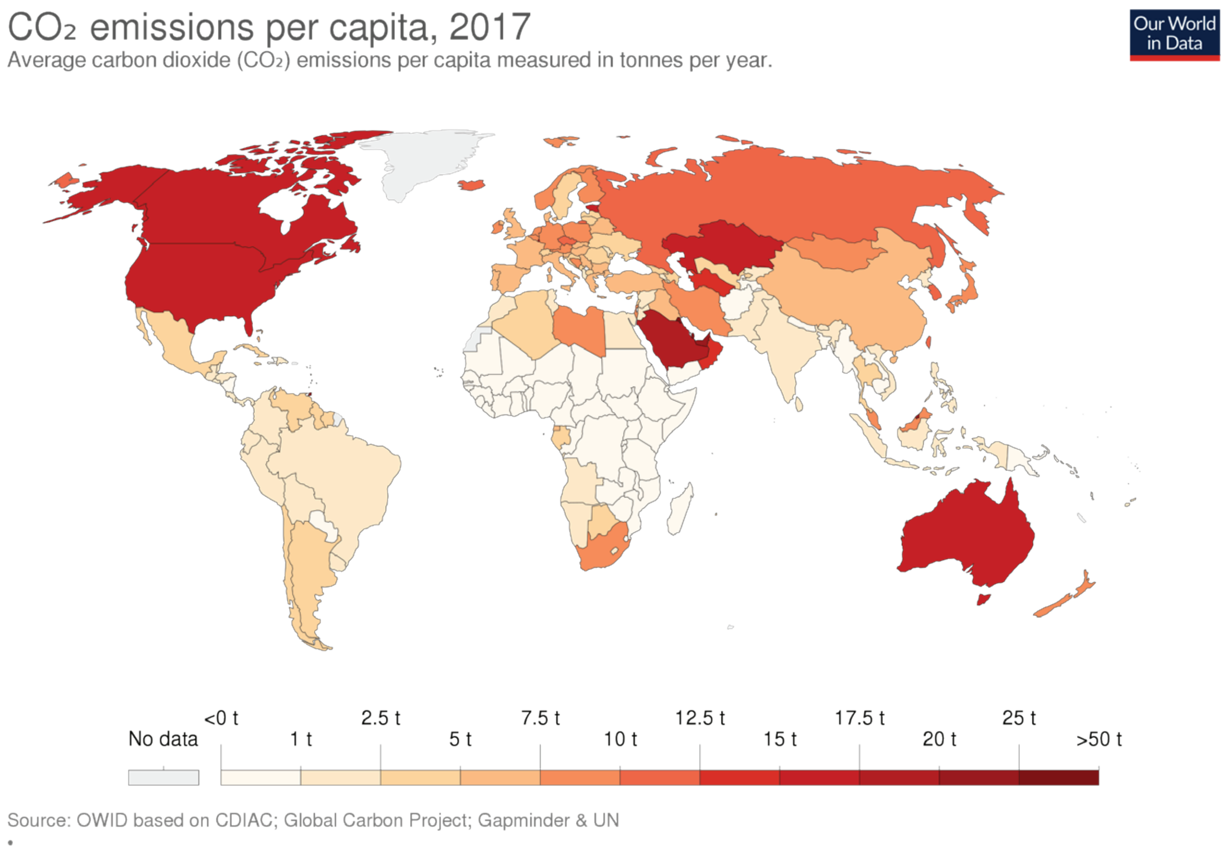
1. Examine the graph, "CO_2 emissions per capita, 2017". This map shows each country's contribution to carbon dioxide emissions.

   a. How many countries are identified as having high carbon dioxide emissions?

Notes for the Facilitator: There are six countries identified as having high carbon dioxide emissions. They are indicated in darker reds.

   b. What are some factors that might cause a country to have greater carbon dioxide emissions than others?

Notes for the Facilitator: Answers may vary, but can include: less available renewable energy sources, larger geographic area so possibly a greater demand on transport, cultural norms. Because this is "per capita," some countries may look the same, but the overall contribution to global emissions is different as the total populations are very different (see the graphs here for more information: https://www.ucsusa.org/resources/each-countrys-share-co2-emissions).



Credit: Our World In Data, Creative Commons

Extensions

1. **Analyzing Data:** There are several sources of methane (CH_4) emissions. As shown in the map, "Methane Emissions by Sector," these include Wetlands; Fossil Fuels; Agriculture and waste; and Biomass and biofuel burning. Examine the maps comparing methane emissions from various industries and natural sources around the world.

   a. Which sector(s) appear to contribute the most methane to the atmosphere?

Notes for the Facilitator: Wetlands or Agriculture & Waste. They have different distributions, but the overall area indicated seems to be about the same.

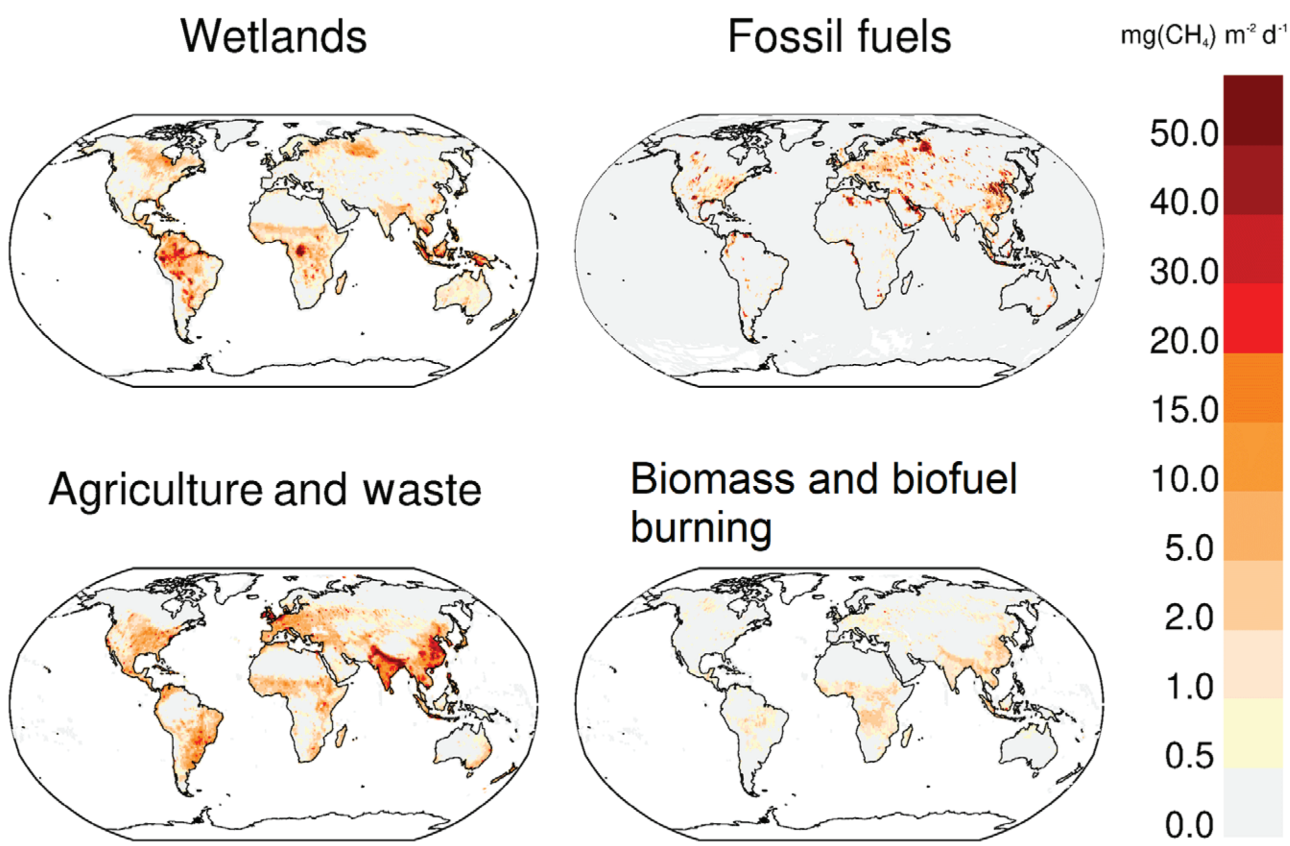
   b. Which industry has methane emissions most similar to carbon dioxide emissions? Explain your reasoning using evidence from the maps.

Notes for the Facilitator: Answers may vary due to the evidence the learners attend to. Fossil Fuels seems to have the most similar distribution when it comes to the darkest colors (minus Australia). The point is for them to recognize that emissions are uneven across the world.

c. Wetlands are natural sources of methane. Why are methane emissions of concern if methane is produced naturally?

Notes for the Facilitator: All the other sectors shown on these maps are not naturally occurring; these sectors are due to human activity. With these sectors adding to methane emissions, levels of methane in the atmosphere are higher than expected, which contributes to a higher-than-normal rate of atmospheric warming.

METHANE EMISSIONS BY SECTOR



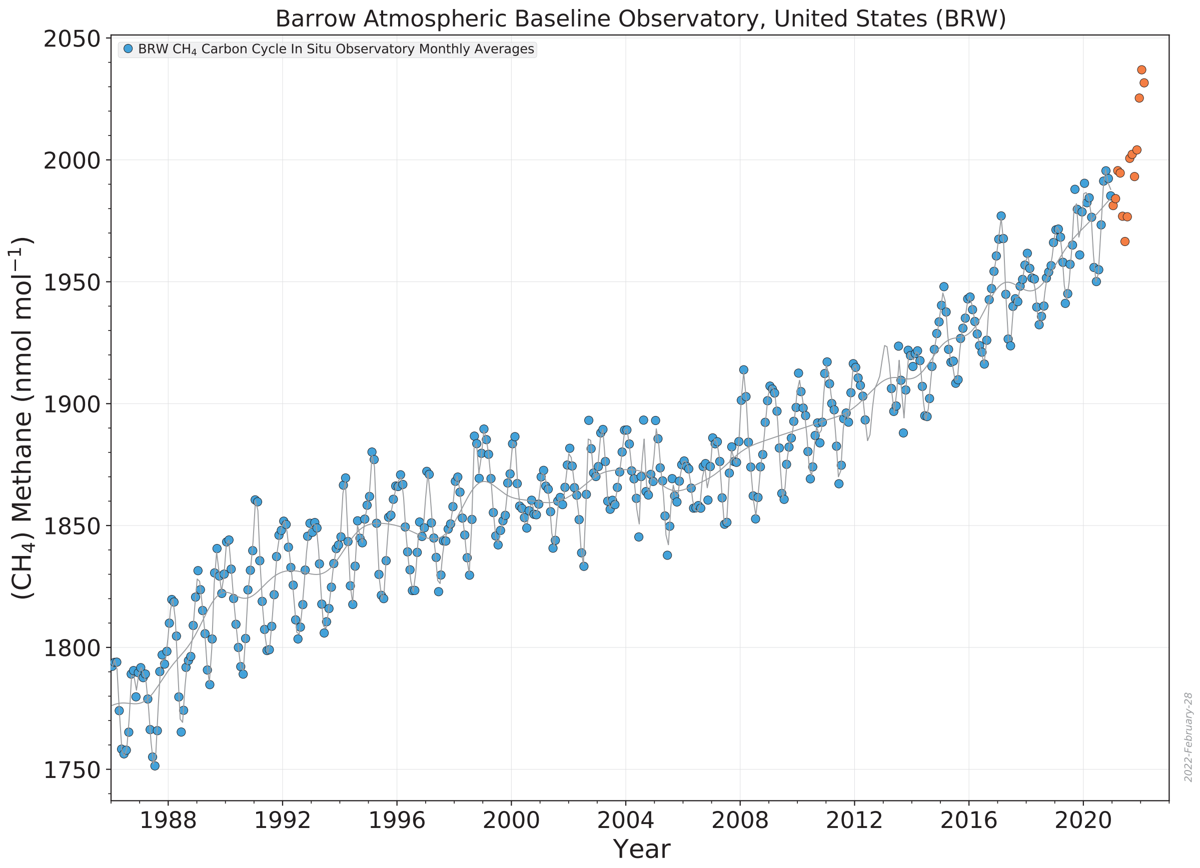
Credit: Modified from Creative Commons, https://commons.wikimedia.org/wiki/File:Map_of_methane_emissions_from_four_source_categories.png

2. **Analyzing Data:** Permafrost is land near the North Pole where the ground stays frozen year-round. Permafrost holds large stores of methane left over from decomposition that was occurring in the soil before the land froze over. As the Earth's climate warms, permafrost has started to thaw.

   a. Use the graph, "Atmospheric Methane Levels near Barrow, Alaska," to describe the effect of permafrost thawing on atmospheric methane levels.

Notes for the Facilitator: The increasing trend on the graph shows that methane levels are rising in the atmosphere. This methane is escaping from the soil under the thawed permafrost.

ATMOSPHERIC METHANE LEVELS NEAR BARROW, ALASKA



Credit: NOAA, **https://gml.noaa.gov/dv/iadv/graph.php?code=BRW&program=ccgg&type=ts(**

b. What effect do you think this methane will have on further thawing of the permafrost? Why do you think this?

Notes for the Facilitator: Methane is a greenhouse gas, so the more that is released, the more the atmosphere will warm, resulting in more permafrost thawing. This is called a positive feedback loop, as a change (warming) results in other changes (permafrost melting, releasing methane) that enhances or reinforces the initial effect (I.e., more methane leads to more warming).

SUSTAINABLE DEVELOPMENT GOALS

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ESD KIT: IMPACTS OF CLIMATE CHANGE

Sustainable Development Goal 13: Climate Action

INVESTIGATION 4A: TESTING THE HEAT CAPACITY OF LIQUIDS

Facilitator Background

Connection to SDG 13: Target 13.3 sets a goal to “improve education...on climate change mitigation, adaptation, impact reduction and early warning” (**https://sdgs.un.org/goals/goal13**). Oceans cover over 70% of the Earth’s surface and hold a majority of the heat Earth receives from the sun, making them a major contributing factor to Earth’s *climate*. Water has the highest heat capacity of any liquid, so it takes more heat to warm water than it does most other substances. Understanding that ocean temperatures change less than air or land temperatures given the same amount of heat can lead to an understanding of the role of oceans in *climate change*. In this Investigation, the heat capacities of different liquids are experimentally examined.

Key Concepts: *climate, climate change*

Learning Outcome: Test the heat capacity of different liquids to understand that the temperature of bodies of water changes slowly compared to air and land.

Connection to the ESD Kit Project: Design a Resilient City: Cities are affected by the climate of their region. Understanding how large bodies of water affect climate is vital for informing people where and how to design cities. Learners can use this Investigation to choose a potential location for the city they design.

PACING GUIDE

PREPARATION
5 minutes setting up the Facilitator Demonstration
10 minutes setting up materials for groups

WHAT TO DO
15 minutes for the Facilitator Demonstration and discussion
20 minutes for each liquid tested in the Investigation

Materials

For Facilitator Demonstration:

- water
- isopropyl alcohol or hand sanitizer (minimum 70% alcohol)
- 2 medicine droppers (syringes or pipettes)
- dark, waterproof surface (desk, chalkboard, or other relatively impervious surface)
- safety goggles
- sunny area (or bright lamp) (optional)
- timer or stopwatch (optional)

For Learner Investigation:

Per group:

- 1 250–500 mL (1–2 cup) heat-resistant glass measuring cup (or beaker)
- plate or tray to carry measuring cup
- 100–250 mL (½-1 cup) water, oil (e.g., vegetable, olive, peanut), and liquid soap
- 1 alcohol thermometer
- 1 hotplate (or microwave)
- boiling stones (if using a microwave, to prevent superheating)
- oven mitts
- safety goggles
- small towel

What to Do

Facilitator Demonstration:

1. Put two drops of water on a dark, waterproof surface. Put two drops of isopropyl alcohol near the water drops.
   a. If using a timer, start it once the drops are placed.
   b. To speed up the process, place the dark surface in a sunny area or under a bright lamp. Alternatively, you can smear the drops so they form a thin layer of liquid, which will also speed evaporation.
2. Describe the setup to learners, then
3. Wait until the isopropyl alcohol completely evaporates.
   a. While waiting, have learners make predictions about what will happen to each liquid as they are left out over time.
   b. If using a timer, mark how long it took for the alcohol to evaporate. If not using a timer, observe that the water has not yet evaporated.

Notes for the Facilitator: Discuss with learners why the alcohol evaporated faster than the water. Water molecules are attracted to each other more strongly than alcohol molecules are attracted to each other. Therefore, it takes more heat to separate water molecules so that they evaporate. This means in the same conditions, alcohol will tend to evaporate faster than water. The Learner Investigation will compare the heat capacity of water to other liquids. Each group can test each liquid, or each group can test one liquid and share their results with the other groups.

Learner Investigation:

1. Fill a heat-proof glass measuring cup (or beaker) halfway with water. Measure and record the initial temperature of the water.
2. Place the measuring cup on a hotplate. Set the hotplate to medium.
    a. If using a microwave, place a boiling chip in the water.
3. Measure and record the temperature of the water. When taking the temperature, carefully hold the thermometer near the middle of the volume of water. Do not let the thermometer sit on the bottom of the measuring cup as that will record the temperature of the glass rather than the temperature of the liquid.
    a. If using a hot plate, measure and record the temperature every 2 minutes for 10 minutes.
    b. If using a microwave, heat the water with boiling stones in 10 second increments for 1 minute 30 seconds. Measure and record the temperature every 10 seconds.
4. Use an oven mitt to carefully remove the measuring cup from the hot plate or microwave and place the measuring cup on the small towel. If using a hotplate, turn it off.

Caution: *Do not touch the glass with your bare hands. Be sure to place the measuring cup on the towel. Do not place the measuring cup on a cold surface, or the glass may shatter.*

5. Measure and record the temperature of the water every 2 minutes for another 10 minutes.
6. Repeat this procedure with each liquid provided.

Notes for the Facilitator: If time allows, measure the temperature of each liquid 30–60 minutes after they have been removed from the heat. This will demonstrate that water both heats and cools slower than other liquids. Other liquids than those listed in the procedure can be used. However, do not test alcohol-based liquids or others that could produce hazardous vapors when heated and/or are highly flammable.

Consider

1. Graph your results on the same axes. Be sure to include axis labels, a descriptive title, and a key.

Notes for the Facilitator: This should be a multiple line graph with time (minutes) on the x-axis and temperature (°C) on the y-axis. Titles will vary, but a good example is "The Change in the Temperature of Different Liquids Over Time." Since there are multiple lines, there should also be a key to identify each line.

2. Consider the rate at which water heats up versus the other liquids you tested. Make a hypothesis to describe the relative rate at which each liquid will cool down. Do you think that liquids that take longer to heat up also take longer to cool down? Why or why not?

Notes for the Facilitator: Since the rate at which a liquid heats up is dependent on its heat capacity, liquids that heat up faster should also cool down faster. Liquids that take longer to heat up (like water) should also take longer to cool down. This has to do with their chemical properties affecting how they transfer heat.

  a. How might Earth be different if a liquid other than water made up our oceans, lakes, and rivers?

  b. How might the temperature change of oceans, lakes, and rivers affect the organisms living in them?

Notes for the Facilitator: Water temperatures in large bodies of water tend to be relatively stable. Other liquids heat and cool faster than water. Organisms living in a liquid other than water would have to be adapted for a wider range of temperatures and more rapid change throughout the day or year. **https://earthobservatory.nasa.gov/global-maps/MYD28M/MY1DMM_CHLORA**. Water also has an important property where the solid form (ice) is less dense than its liquid form, so bodies of water freeze from the top down. The ice layer can then insulate the water underneath and prevent larger bodies of water from freezing completely, which has important implications for aquatic life.

  c. Large bodies of water moderate the climate of nearby lands, meaning being nearby an ocean, bay, or large lake helps keep the temperature of the nearby land relatively stable. How might this change if the bodies were made of something other than water?

Notes for the Facilitator: Water holds heat well, which is why large bodies of water moderate the temperature of nearby land. If these bodies of water had another liquid that heated and cooled faster, then the nearby land would do the same, and their temperature would no longer be held stable.

Extensions

1. **Testing Variables:** Predict how your results might change if you used salt water instead of fresh water. Test your prediction and compare the results to that of fresh water.

Notes for the Facilitator: The salinity of ocean water is about 3.5% by weight. Adding 3.5 grams of salt to 100 mL of water will provide a model of ocean water.

2. **Testing Variables:** Predict how your results might change if you tested a larger volume of each liquid. Test your prediction and compare your results to the original volume you tested.

Notes for the Facilitator: While larger volumes of liquid may take longer to heat (and cool down), the same trend should be observed, and water will heat and cool slower than other liquids. This can be related to the difference between living next to a small pond, a large lake, or the ocean.

3. **Analyzing Data:** Go to: **https://earthobservatory.nasa.gov/global-maps/MYD28M/AMSRE_SSTAn_M**

  a. Before viewing the animation, study the Sea Surface Temperatures color key.

b. Play the animation and observe the Sea Surface Temperatures animation. Describe any yearly patterns or trends you see in sea surface temperature. It may help to focus your attention on a part of the ocean near where you live, or someplace else that interests you.

Notes for the Facilitator: The highest temperatures are near the equator and decrease toward each pole. The moderate and lower temperatures shift in a yearly pattern; warmer temperatures drift south from November to April and north from May to October.

c. Study the color key for the Sea Surface Temperature Anomaly map.

d. Play the animation and observe the Sea Surface Temperature Anomaly animation. It may help to focus your attention on a part of the ocean near where you live, or someplace else that interests you.

e. What is happening to average sea surface temperatures? Describe any changes or trends you see over time.

f. How do the two maps compare?

Notes for the Facilitator: Temperatures that are higher than expected occur more frequently near the north pole from 2002–2005, but in 2006 start to become more common around the world. By 2009, there are many areas with warmer than expected temperatures than cooler. Lower than expected occur regularly in June and July off the west coast of South America. Both maps show patterns, which are due to the tilt of the Earth that affects sunlight hitting the Earth in different areas, which then affects wind and water circulation patterns.

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INVESTIGATION 4B: COASTAL STORMS

Facilitator Background

Connection to SDG 13: Target 13.1 is designed to “strengthen resilience and adaptive capacity to climate-related hazards” (**https://sdgs.un.org/goals/goal13**). Warmer ocean temperatures are thought to play a role in the strengthening of storms, especially hurricanes and cyclones, making them *climate-related hazards*. Coastal cities are impacted by these storms, and so must have *adaptations* built in to prevent excess damage to the city; what’s known as *impact reduction*. Countries and cities that invest in adaptive structures will have a greater resilience in the face of climate change.

Key Concepts: *adaptation, climate-related hazards, impact reduction*

Learning Outcome: Design and evaluate the effectiveness of seawalls as a mitigation strategy for coastal storms.

Connection to the ESD Kit Project: Design a Resilient City: Coastal cities have unique challenges when it comes to designing adaptive strategies for combating the effects of climate-related hazards. Coastal flooding and storms are of particular concern. Understanding adaptations that can help reduce the impact of these events will help learners design a more resilient city.

PACING GUIDE

PREPARATION

10 minutes setting up the Facilitator Demonstration
10 minutes setting up materials for groups

WHAT TO DO

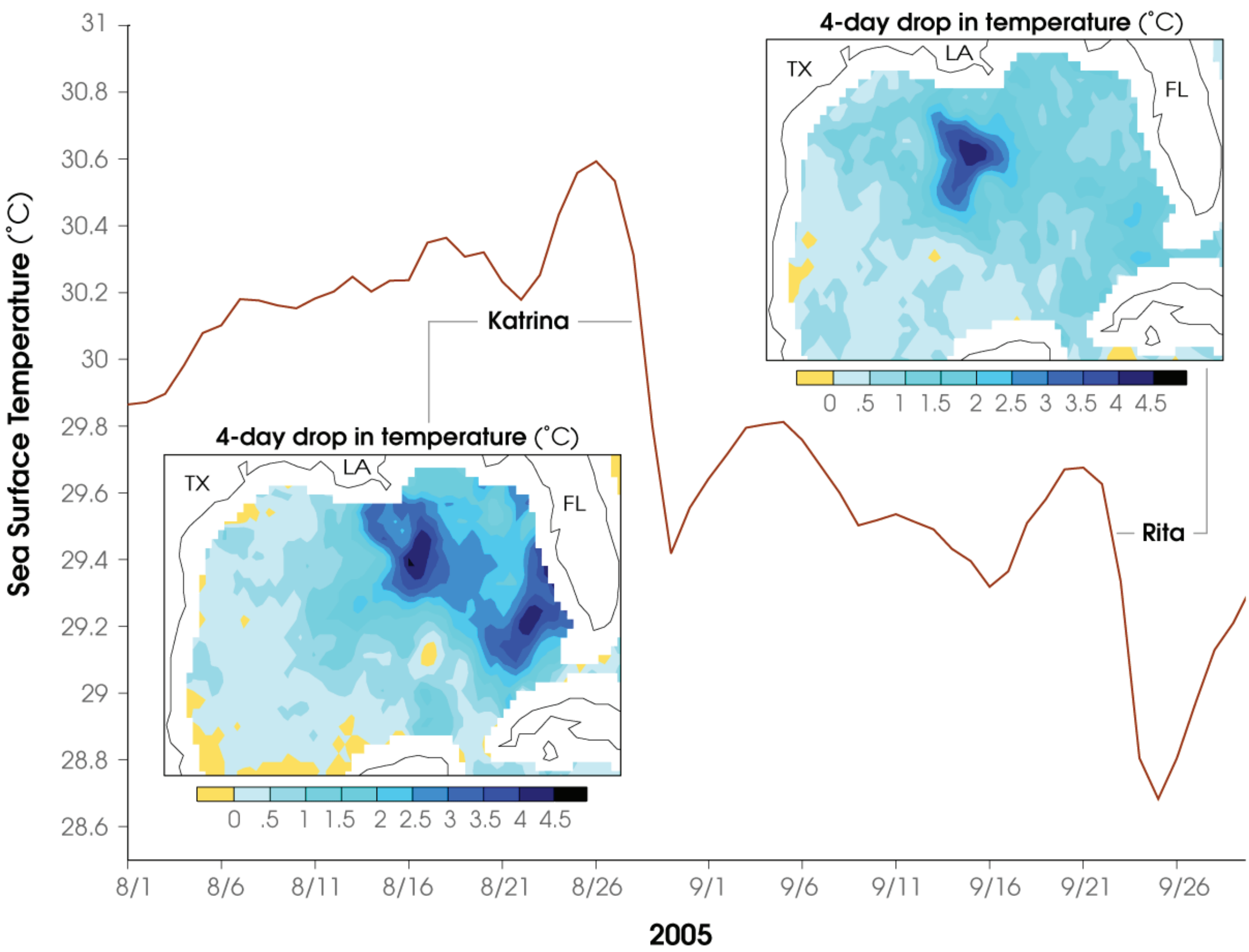
10 minutes for the Facilitator Demonstration and discussion
10 minutes discussing the introduction material
30 minutes for the Investigation

Notes for the Facilitator: For learners to get the most out of this Investigation, they should have already completed Investigation 4A. In Investigation 4A, the Extension: Data Analysis makes connections between the heat capacity of water and average sea temperatures. If learners did not complete the extension, show images of sea surface temperatures taken at two different times of the year, and discuss before completing Investigation 4B: **https://mpt.pbslearningmedia.org/resource/clim10.sci.ess.watcyc.seasurftemp/the-effect-of-sea-surface-temperature-on-hurricanes/**

Introduction

The strength of hurricanes is affected by water temperatures. Warmer water evaporates faster from the surface of the ocean and can cause a more rapid change in pressure, winds, and precipitation that allows a hurricane to grow stronger. The graph "Temperature Changes in the Gulf of Mexico Following Hurricanes Katrina and Rita" shows that after both hurricanes Katrina and Rita, the average temperature of the Gulf of Mexico dropped 1ºC (1.8ºF). Some areas of the Gulf dropped as much as 4ºC (7.2ºF), as shown in dark blue. Both hurricanes were a category 5 while over the Gulf and dropped to a category 3 by landfall. While there are many variables that factor into the strength of storms, it is thought that the strength of these hurricanes was due, in large part, to warm water temperatures.

TEMPERATURE CHANGES IN THE GULF OF MEXICO FOLLOWING HURRICANES KATRINA AND RITA



Credit: NASA Earth Observatory, https://earthobservatory.nasa.gov/images/6223/passing-of-hurricanes-cools-entire-gulf

Notes for the Facilitator: A good resource on the link between higher sea temperatures and the strength of storms can be found here: https://mpt.pbslearningmedia.org/resource/clim10.sci.ess.watcyc.seasurftemp/the-effect-of-sea-surface-temperature-on-hurricanes/

The destructive force of a hurricane is something that city planners need to address in coastal regions. Mitigation and adaptation strategies have been developed to combat both flooding and storm surges, which are storm-driven rises in ocean water level above expected tides that can lead to water flooding over coastal areas.

Notes for the Facilitator: Two similar tests will be run during this Investigation; Group A tests coastal erosion and Group B tests coastal flooding. All learners could complete both setups or learners can be split to complete one procedure and then share their results with the other group. Have learners test as many seawall designs as possible to get a range of results.

Materials

For Facilitator Demonstration:

- 2 balloons with about a 30 cm (12”) diameter
- water
- lighter (needs a flame, not a forceful jet)
- large basin or plastic bin
- safety goggles

For Learner Investigation:

Per group:

- clear plastic bin (approximately 35 cm x 25 cm (14 in x 10 in) and 10–15 cm (4–6 in) deep)
- water
- small dowels, toothpicks, popsicle sticks, small rocks, or other materials that can be used to build a seawall
- empty 500 mL (16.9 oz) water bottle
- ruler
- construction paper
- tape
- washable markers (different colors)
- metronome (or recording of a steady beat)
- modeling clay
- fine-grained sand (Group A)
- pebbles or coarser sand (Group B)

What to Do

Facilitator Demonstration:

1. Inflate one balloon to approximately half full. Tie the end.
2. Fill the other balloon with water so it is about the same size as the air-filled balloon. Try to eliminate any large air pockets. Tie the end.
3. Have learners make predictions about what will happen to the air-filled balloon when a flame is held to it.

Notes for the Facilitator: Take proper precautions when using fire. Goggles should be worn for safety and to demonstrate safety practices to learners.

4. Hold the air-filled balloon by the neck, allowing the body of the balloon to hang down.
5. Hold a flame to the body of the balloon. The balloon will pop (which should be almost immediate).
6. Ask the learners why they think the balloon popped.

Notes for the Facilitator: They will likely suggest that the heat from the flame damaged the balloon. The balloon pops because the air inside doesn't absorb much heat, so all the heat is absorbed by the rubber of the balloon. This heat causes the balloon to melt (or burn), creating a weak spot that is pulled open by the tension of the balloon material.

7. Have learners make predictions about what will happen with the water-filled balloon.

8. Hold the water-filled balloon by the neck, allowing the balloon to hang down over a basin to catch the water when the balloon pops.

9. Hold a flame to the body of the balloon, making sure the flame is targeted on an area of the balloon that is touching water and not an air pocket.

10. Ask the learners what they observed.

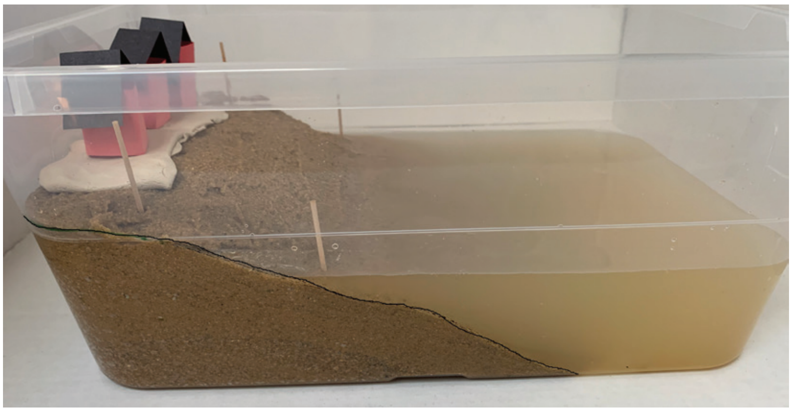
Notes to the Facilitator: It is suggested that facilitators try this before completing it with learners; this will help estimate the time it takes for the balloons to pop. The water-filled balloon will eventually pop, but learners should observe that it takes much longer than it did with the air-filled balloon. If the heat is not applied long enough to get the balloon to pop, show learners the soot spot on the balloon to show evidence that heat was applied but still did not affect the balloon. Have learners hypothesize why given what they observed in the Learner Investigation, with water changing temperature more slowly than other liquids. Water has a high heat capacity and can absorb a great deal more heat than air before it starts to heat up. The rubber of the balloon was still absorbing heat, but since the water was absorbing the heat from the balloon, the balloon took longer to be damaged and pop.

Learner Investigation:

(Directions for 2 groups listed starting on next page.)

GROUP A

1. In a plastic bin, build a model beach by piling moist, fine-grained sand in a plastic bin.
   a. The highest point of the sand should be along one of the bin's shorter walls. The sand should be a little over half the height of the bin and should have a relatively flat surface along the short side of the bin.
   b. Make a "hill" by angling the sand down toward the middle of the bin.
2. Use a washable marker to make an outline of the shape of the sand on the outside of the bin.
3. Add water to the bin until it comes about halfway up the sand. Push a toothpick or small dowel into the sand at the water line to mark where the exposed model beach starts.
4. Place a layer of modeling (plasticene) clay at the top of the beach to model paved surfaces, and also to prevent the houses from getting wet before waves are generated.
5. Build 2–4 small houses from construction paper. Place them on the layer of clay. Place a toothpick or small dowel to mark the location of the front of the houses.



Credit: L.C. Mossa

6. Make waves using an empty water bottle.
   a. Gently lay the bottle on its side in the water, as far from the beach as possible.
   b. Push the bottle down approximately 2 cm to make a wave, then let it float up. Repeat this to make more waves at a steady rate.
   c. Using a metronome will help to keep a constant rhythm for your waves.
   d. Continue bobbing the bottle for 2 minutes to see the effects the waves have on the beach and houses.
7. Analyze the new sand profile.
   a. Use a different color marker to trace the new sand profile.
   b. Make observations of how the beach has changed, if the location of the beach has changed (i.e., how high up the water meets the sand), and if the houses have gotten wet or moved.
8. Reset the sand to its original position.
   a. Reset the toothpick indicating the water line and house locations.

b. Replace any houses that got wet.

9. Use the available supplies to build a wall that will prevent the beach from changing. This will be a model seawall for your coastal community.

10. Make waves for another two minutes, then make observations on any changes that occurred.

11. Based on your results, determine what modifications could be made to your seawall that could make it more effective. Test one possible modification, being sure to reset the beach to its original location before testing.

12. Make waves for another two minutes, then make observations on any changes that occurred.

13. Share your design and results with the whole group.

Consider

1. Once you built the seawall, how did the changes that occurred compare to the changes in your original test?

Notes for the Facilitator: Answers will vary but will likely include that there was less or slower erosion of the beach and that the houses were protected from the waves.

a. After listening to other seawall designs, what modifications would you make to your design? Why?

Notes for the Facilitator: Answers will vary. Learners should focus on the shape and size of the seawall to get the most effective design.

2. Compare the results of Group A and Group B. Did the same style of seawall work for both beaches? Why do you think this is?

Notes for the Facilitator: Answers will vary, but it is likely that the two beaches required different seawalls. Larger sediment or rocks would be less prone to erosion and so would probably require a smaller seawall.

3. Is your area affected by coastal flooding? If so, are there any areas in your community that would benefit from a seawall? If there are already seawalls near you, what modifications could be made to improve them?

Notes for the Facilitator: If your area is not affected by coastal flooding, learners could look at images of seawalls and suggest improvements.

4. Look at a map of your country. What coastal places do you visit or consider interesting? Do you think they would benefit from a seawall? How could you find out?

Notes for the Facilitator: Answers will vary depending on the locations learners choose. Research will likely be required to address these questions.

5. Besides building a seawall, what other variables could be changed to keep the water from flooding the houses?

Notes for the Facilitator: Possible ideas include building the houses on stilts or using other materials to make the houses more resilient. Reefs (including oyster reefs) just offshore or plants on the shore can also help mitigate erosion and flooding.

Extensions

1. **Testing Variables:** Predict which is more effective: a thicker seawall or a taller seawall. Test different designs to see their effects on erosion of the beach. Be sure to rebuild the original beach before testing each time.

2. **Testing Variables:** Living seawalls are a more natural means of preventing coastal flooding and erosion. The image shows a mangrove forest on a beach in Zanzibar that acts as a seawall.

Credit: Flickr/GRID-Arendal resources library photo by Rob Barnes, CC BY-NC-SA 2.0 DEED. https://www.grida.no/resources/8701

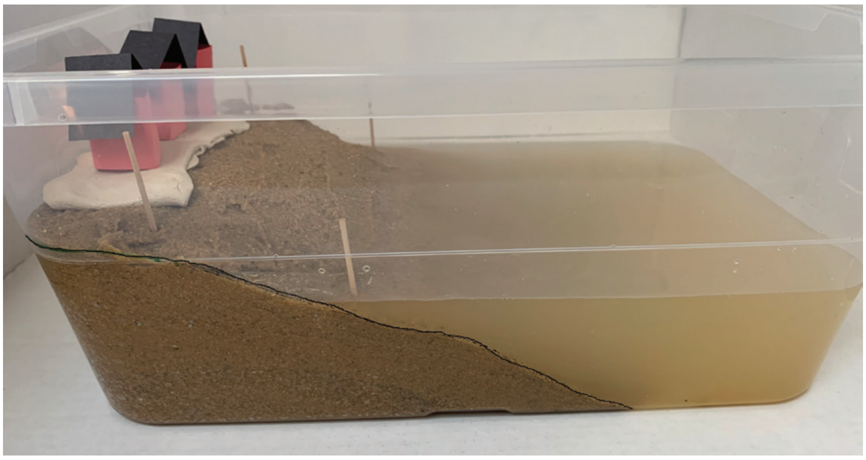
   a. How do you think plants help prevent flooding and beach erosion?

Notes for the Facilitator: The roots of the plants hold the soil in place, preventing erosion. The plants can also absorb the force of the waves and dissipate the energy, which also reduces erosion in addition to slowing the movement of water, helping to prevent coastal flooding. The plants also use some of the water and their roots break through the soil enough to give more space for water to infiltrate the land, which can also help reduce flooding.

   b. Use small plastic aquarium plants to construct a seawall for your beach. How does it compare the seawalls you designed in terms of preventing erosion and flooding?

GROUP B

1. In a plastic bin, build a model beach by piling moist, coarse-grained sand or pebbles in a plastic bin.
   - **a.** The highest point of the sand should be along one of the bin's shorter walls. The sand should be a little over half the height of the bin and should have a relatively flat surface along the short side of the bin.
   - **b.** Make a "hill" by angling the sand down toward the middle of the bin.
2. Use a washable marker to make an outline of the shape of the sand on the outside of the bin.
3. Add water to the bin until it comes about halfway up the sand. Push a toothpick or small dowel into the sand at the water line to mark where the exposed model beach starts.
4. Place a layer of modeling (plasticene) clay at the top of the beach to model paved surfaces, and also to prevent the houses from getting wet before waves are generated.
5. Build 2–4 small houses from construction paper. Place them on the layer of clay. Place a toothpick or small dowel to mark the location of the front of the houses.



Credit: L.C. Mossa

6. Make waves using an empty water bottle.
   - **a.** Gently lay the bottle on its side in the water, as far from the beach as possible.
   - **b.** Push the bottle down approximately 2 cm to make a wave, then let it float up. Repeat this to make more waves at a steady rate.
   - **c.** Using a metronome will help to keep a constant rhythm for your waves.
   - **d.** Continue bobbing the bottle for 2 minutes to see the effects the waves have on the beach and houses.
7. Analyze the new sand profile.
   - **a.** Use a different color marker to trace the new sand profile.
   - **b.** Make observations of how the beach has changed, if the location of the beach has changed (i.e., how high up the water meets the sand), and if the houses have gotten wet or moved.

8. Reset the sand to its original position.
   a. Reset the toothpick indicating the water line and house locations.
   b. Replace any houses that got wet.
9. Use the available supplies to build a wall that will prevent the beach from changing. This will be a model seawall for your coastal community.
10. Make waves for another two minutes, then make observations on any changes that occurred.
11. Based on your results, determine what modifications could be made to your seawall that could make it more effective. Test one possible modification, being sure to reset the beach to its original location before testing.
12. Make waves for another two minutes, then make observations on any changes that occurred.
13. Share your design and results with the whole group.

Consider

1. Once you built the seawall, how did the changes that occurred compare to the changes in your original test?

> **Notes for the Facilitator:** Answers will vary but will likely include that there was less or slower erosion of the beach and that the houses were protected from the waves.

2. After listening to other seawall designs, what modifications would you make to your design? Why?

> **Notes for the Facilitator:** Answers will vary. Learners should focus on the shape and size of the seawall to get the most effective design.

3. Compare the results of Group A and Group B. Did the same style of seawall work for both beaches? Why do you think this is?

> **Notes for the Facilitator:** Answers will vary, but it is likely that the two beaches required different seawalls. Larger sediment or rocks would be less prone to erosion and so would probably require a smaller seawall.

4. Is your area affected by coastal flooding? If so, are there any areas in your community that would benefit from a seawall? If there are already seawalls near you, what modifications could be made to improve them?

> **Notes for the Facilitator:** If your area is not affected by coastal flooding, learners could look at images of seawalls and suggest improvements.

5. Look at a map of your country. What coastal places do you visit or consider interesting? Do you think they would benefit from a seawall? How could you find out?

> **Notes for the Facilitator:** Answers will vary depending on the locations learners choose. Research will likely be required to address these questions.

6. Besides building a seawall, what other variables could be changed to keep the water from flooding the houses?

> **Notes to the Facilitator:** Possible ideas include building the houses on stilts or using other materials to make the houses more resilient. Reefs just offshore or plants on the shore can also help mitigate erosion and flooding.

Extensions

1. **Testing Variables:** Predict which is more effective: a thicker seawall or a taller seawall. Test different designs to see their effects on erosion of the beach. Be sure to rebuild the original beach before testing each time.

2. **Testing Variables:** Living seawalls are a more natural means of preventing coastal flooding and erosion. The image shows a mangrove forest on a beach in Zanzibar that acts as a seawall.

Credit: Flickr/GRID-Arendal resources library photo by Rob Barnes, CC BY-NC-SA 2.0 DEED. https://www.grida.no/resources/8701

   a. How do you think plants help prevent flooding and beach erosion?

Notes for the Facilitator: The roots of the plants hold the soil in place, preventing erosion. The plants can also absorb the force of the waves and dissipate the energy, which also reduces erosion in addition to slowing the movement of water, helping to prevent coastal flooding. The plants also use some of the water and their roots break through the soil enough to give more space for water to infiltrate the land, which can also help reduce flooding.

   b. Use small plastic aquarium plants to construct a seawall for your beach. How does it compare the seawalls you designed in terms of preventing erosion and flooding?

ESD KIT: IMPACTS OF CLIMATE CHANGE

Sustainable Development Goal 13: Climate Action

INVESTIGATION 5A: ICE MELTING, THERMAL EXPANSION, AND SEA LEVEL RISE

Facilitator Background

Connection to SDG 13: Target 13.3 calls attention to the need for "early warning" indicators in terms of environmental changes caused by climate change (**https://sdgs.un.org/goals/goal13**). *Early warning* measures include the monitoring of environmental changes so that alerts can be provided to communities when a hazard emerges. Sea level rise has been occurring at a faster-than-ever rate for the last 100 years. The accumulation of greenhouse gases in the atmosphere causes temperatures to rise, which leads to thermal expansion of bodies of water, as well as melting of glaciers and ice caps. In this Investigation thermal expansion is demonstrated by the facilitator, and then learners test and extrapolate how melting ice contributes to rising sea levels.

Key Concepts: *early warning*

Learning Outcome: Determine how heat and ice melting can contribute to sea level rise by observing and testing variables.

Connect to the ESD Kit Project: Design a Resilient City: Cities have historically been built near bodies of water due to the need to transport materials. This Investigation can inform the learners' decision as to where to design their cities in relation to bodies of water.

PACING GUIDE

PREPARATION
10 minutes cutting foam blocks
10 minutes freezing large ice blocks
10 minutes setting up materials for groups

WHAT TO DO
20 minutes conducting and discussing the Facilitator Demonstration
45 minutes for the Investigation

Introduction

Icebergs are large masses of ice floating in waterways, particularly oceans. They are most commonly found in the North Atlantic near Greenland, as well as near Antarctica; especially during the summer months in each of these hemispheres as ice sheets and glaciers are warmed. Icebergs form when large pieces of ice shelves or glaciers break off. Many icebergs can migrate when they are carried by ocean circulation, but not all do.

Glaciers are large masses of ice found on land. While they can occur at the tops of mountains, glaciers are more commonly found near the arctic and Antarctic. Continental glaciers are extremely large, and cover entire landmasses, such as those found on Greenland and Antarctica. Glaciers typically expand in colder months as water freezes, but then shrink or retreat again in warmer months, as some of their ice melts.

Materials

For Facilitator Demonstration:

- 500 mL Erlenmeyer flask
- rubber stopper with two holes (to fit in top of flask)
- thin glass tubing (must fit securely in one hole of the rubber stopper)
- thermometer (must fit through one hole of the rubber stopper)
- cold water
- desk lamp with incandescent bulb (or area with direct sun)
- ruler
- permanent marker (preferably black and fine tip)
- food coloring (optional)

For Learner Investigation (per group):

- plastic bin [approximately 35 cm x 25 cm (14 in x 10 in) and 10–15 cm (4–6 in) deep]
- closed cell foam block (approximately half the height and length of the bin)
- desk lamp
- saltwater (35 g salt/L of water [1/3 cup of salt per 4 1/3 cup of water])
- large ice block containing food coloring
- washable marker
- ruler
- weight (optional)
- mass scale (optional)

What to Do

Facilitator Demonstration:

1. Put cold water in the Erlenmeyer flask so that it comes up to where the bottom of the rubber stopper will be when it is securely on the flask. Add food coloring, if available.
2. Lay a ruler alongside the glass tubing and mark each centimeter using a permanent marker.
3. Carefully insert the glass tubing into one hole of the stopper and the thermometer into the other. The tubing and thermometer should reach the middle of the Erlenmeyer flask.

Notes for the Facilitator: Safety guidelines for how to insert glass tubing into a rubber stopper can be found here: **https://www.labmanager.com/lab-health-and-safety/the-correct-way-to-insert-glass-tubing-or-a-thermometer-into-a-stopper-19458**

4. Place the rubber stopper securely on the flask. Have learners watch the glass tubing as you place the stopper. Ask them what they see happening.

5. Measure the temperature of the water.

6. Measure how far the water moves up the glass tubing. Make note of the place on the glass tubing where the water ends. If you were not able to make markings on the glass tubing, you can use a ruler to estimate these measurements.

7. Have learners predict what will happen to the water in the tube when the flask is heated by a lamp or direct sunlight.

8. Place the desk lamp 5 cm (2 inches) from the side of the flask, with the bulb pointed toward the flask. Alternatively, you can place the flask in direct sunlight, although it may take longer to get results.

9. Measure the height of the water in the tubing every 2 minutes for 10 minutes total.

10. Discuss as a class what the learners saw happen and why they think it did.

Notes for the Facilitator: The heated water goes up the tube because water expands as it warms, so it takes up more space. Do not focus on the water rising, as this may be misleading, but instead describe expansion in terms of the water molecules spreading out. The tubing made it easier to see this, since the relatively small volume of water in the flask would not expand enough to actually see the water rise up the flask.

Learner Investigation:

Notes for the Facilitator: This Investigation is designed for learners to complete one of the two procedures and compare results. The ice blocks used should all be approximately the same size regardless of which procedure is being done.

GROUP A: GLACIERS

In this Investigation, you will model a glacier.

1. Place a foam block at one end of the plastic bin.

> **Notes for the Facilitator:** The best type of foam to use would be a stiff, closed-cell foam, similar to that used in floral arrangements. If the foam floats, use a weight to hold it down.

2. Measure the length, width, and height of the ice block. If you have a scale, take the mass of the ice block
3. Place the ice block on top of the foam block.
4. Fill the bin with saltwater so it comes about halfway up the foam block.
5. Mark the water level on the foam block and on the side of the bin. Measure the water level using a ruler.

> **Notes for the Facilitator:** It would be beneficial to have all groups use the same initial water height.

6. Set up the lamp so that it is directly over the block of ice.
7. Take measurements every 5 minutes for 30 minutes.
    a. Mark the water level.
    b. Measure the length, width, and height of the ice block. If you have a scale, take the mass of the ice block and quickly return it to the foam block. Observe any changes in shape.
    c. If the ice contains food coloring, observe where the water from the ice goes.

> **Notes for the Facilitator:** As the learners are conducting the experiment, they can begin creating their graph described in Consider number 1, below. Alternatively, they could work on the Extension.

8. Discuss your results with the whole group. As groups share, consider differences between the results of the iceberg compared with the glacier.

Consider

1. Graph the water height over time. Make sure your graph has a descriptive title and labeled axes.

> **Notes for the Facilitator:** Graphs will vary. The x-axis should be labeled Time (min), while the Y-axis should be labeled Water Height (cm). A good title would be: Water Height Change over Time due to Melting of Ice From Different Sources.

2. 2. Compare the results from glaciers and icebergs.
    a. Which melted faster? Why do you think this is?

Notes for the Facilitator: The glacier is expected to melt first. The glacier is directly exposed to the air while the iceberg is surrounded by water. The air around the glacier will heat up more quickly than the water around the iceberg, so the iceberg will not melt as fast. Although, in real life, there can be considerable differences in the maximum thicknesses and areas of glaciers vs icebergs – the thickest known icebergs are thinner than the average Antarctic ice sheet, which also covers a much larger area, so the volumes involved are very different. Air at the poles especially can get much colder than water can.

b. Which contributed more to a rise in water level? Why do you think this is?

Notes for the Facilitator: The glacier should contribute more to a rise in water level because it is on land, so all the water it produces is added to the sea level. The Iceberg is already partially submerged in water, so the only water it contributes to the rise in sea level is the part of the ice that was above the water when the experiment started. This is also why a full glass with free-floating ice in it will not overflow as the ice melts.

Extension

1. **Analyzing Data:** The graph "Global Temperature Anomaly" represents Earth's average temperature (taken between 1951 and 1980) as the x-axis, while the bars show how much Earth's average temperature deviated from that average each year. The graph "Cumulative Mass Change of Glaciers Over Time" shows the total change in mass of glaciers found on different landmasses in meters of water equivalent (m w.e), a unit that shows mass loss. Meters of water equivalent represents the volume of water that would be obtained from the melting snow or ice and is used to compare different glaciers to normalize measured thicknesses for different snowpack densities.

   a. Describe the trend in Earth's average temperature from 1940–2020.

Notes for the Facilitator: The average temperature was less than 0.25ºC over the average in the 1940s. For most of the 1950s through the 1970s, the temperature was near or lower than average. From the late 1970s to the present, the temperature has been increasingly higher than average, with the last 7 years shown on the graph being around 1ºC over average.

   b. Which glaciers have been most affected by the change in Earth's average temperature between 1940 - 2020? How can you tell? Use evidence from the graph to support your answer.

Notes for the Facilitator: Overall change in mass should be determined by comparing the start and end point of each line. For example, the line for Alaska starts right under 0 m w.e. and ends near –34 m w.e.; this overall is the greatest change. The Pan Arctic and N. Scandinavia glaciers both ended near –23 m w.e., and so were the second-most-affected glaciers.

c. Which glaciers have been least affected by a rise in Earth's average temperature? Use evidence from the graph to support your answer.

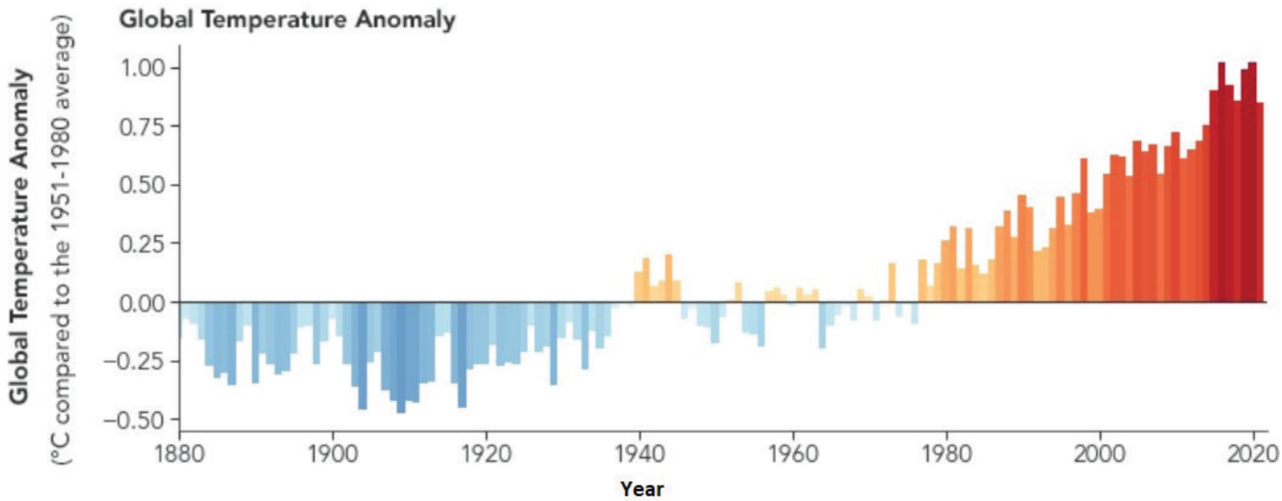
Notes for the Facilitator: The line for Arctic Canada starts near 0 m w.e. and ends at -12 m w.e.; this is the glacier that has changed the least out of those shown. There is a 5 m w.e. gap between the loss from the Arctic Canada glacier and all the others shown.

d. The rate of change of the glaciers is shown by how steep the lines are. Why do you think not all glaciers are melting at the same rate?

Notes for the Facilitator: Rate takes time into account, rather than just looking at the overall change in the glaciers mass loss. The slope (steepness) can give an indication of rate. The line for Iceland is steepest from 2000–2011, and the line for Alaska is steepest from 1993 – 2019, indicating a faster rate of ice loss than other glaciers. Actual rates can be calculated by dividing change over time. The Alaska glacier dropped from –8 m w.e. in 1993 to –34 m w.e. in 2019. This is a change of –26 m w.e. over 26 years, which would be a rate of approximately –1 m w.e./year. In contrast, the Alaska glacier dropped from –1 m w.e. in 1954 to -8 m w.e. in 1993. This is a change of –7 m w.e. over 39 years, which gives a rate of –0.18 m w.e./year, which is a much lower rate of loss. The loss of ice from glaciers is due to the temperature of their environment. Glaciers can be affected by seasonal changes, whether or not they are close to a large body of water that moderates their environmental temperature, how large the glacier is (thicker ice may not melt as fast), and how much their environment has been warmed by climate change.

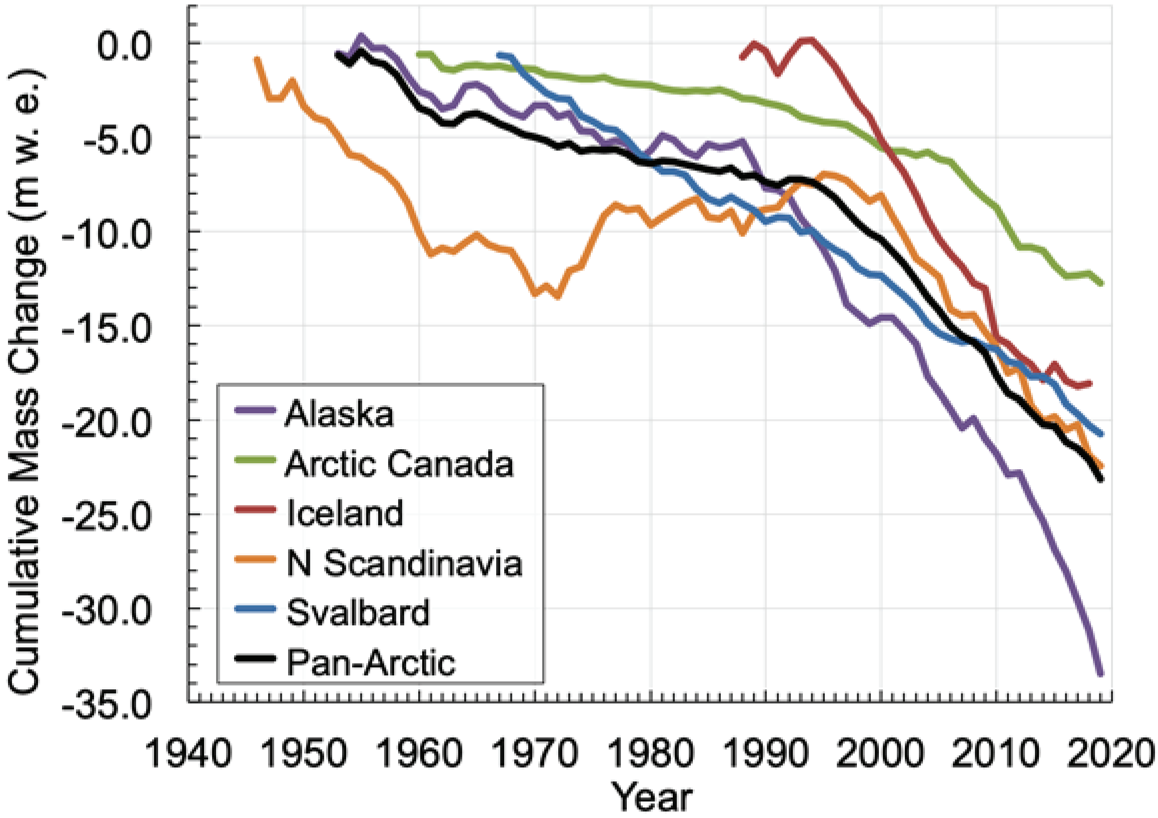
e. Glaciers are found on land. How does their melting contribute to sea level rising?

Notes for the Facilitator: As glaciers melt, the water that runs off them forms streams or enters groundwater or rivers, all of which eventually flow to the ocean and contribute to sea level rise.



Credit: NASA, https://earthobservatory.nasa.gov/images/147794/2020-tied-for-warmest-year-on-record

CUMULATIVE MASS CHANGE OF GLACIERS OVER TIME



Credit: NOAA, **https://arctic.noaa.gov/Report-Card/Report-Card-2020/ArtMID/7975/ArticleID/906/Glaciers-and-Ice-Caps-Outside-Greenland**

GROUP B: ICEBERGS

In this Investigation, you will model an iceberg.

1. Place the foam block at one end of the plastic bin.

2. Fill the bin with saltwater so it comes about 1/3 up the foam block. You may need to place an object on the foam block to prevent it from floating.

Notes for the Facilitator: It would be beneficial to have all groups use the same initial water height in the bin.

3. Measure the length, width, and height of the ice block. If you have a scale, take the mass of the ice block.

4. Place the ice block in the water.
   a. Observe the water level as you place the ice block into the water.
   b. If needed, add more saltwater until it comes halfway up the foam block.
   c. Mark the level of the water on the foam block and on side of the bin. Measure the water level with a ruler.
   d. Measure how much of the ice block is above the water.

5. Set up the lamp so that it is directly over the block of ice. Be careful not to bump the bin so that the ice stays directly under the lamp.

6. Take measurements every 5 minutes for 30 minutes.
   a. Mark the water level on the foam block and on the side of the bin.
   b. Measure the length, width, and height of the ice block. If you have a scale, take the mass of the ice block and quickly return to the water under the light. Observe any changes in shape.
   c. Measure how much of the ice block is above the water.
   d. If the ice contains food coloring, observe where the water from the ice goes.

Notes for the Facilitator: As the learners are conducting the experiment, they can begin creating their graph described in Consider number 1, below. Alternatively, they could work on the Extension.

7. Discuss your results with the whole group. As groups share, consider differences between the results of the iceberg compared with the glacier.

Consider

1. Graph the water height over time. Make sure your graph has a descriptive title and labeled axes.

Notes for the Facilitator: Graphs will vary. The x-axis should be labeled Time (min), while the Y-axis should be labeled Water Height (cm). A good title would be: "Water Height Change Over Time Due to Melting of Ice From Different Sources."

2. Compare the results from glaciers and icebergs.
   a. Which melted faster? Why do you think this is?

Notes for the Facilitator: The glacier is expected to melt first. The glacier is directly exposed to the air, whereas the iceberg is surrounded by water. The air around the glacier will heat up more quickly than the water around the iceberg, so the iceberg will not melt as fast.

b. Which contributed more to a rise in water level? Why do you think this is?

Notes for the Facilitator: The glacier should contribute more to a rise in water level because it is on land, so all the water it produces is added to the sea level. The Iceberg is already partially submerged in water, so the only water it contributes to the rise in sea level is the part of the ice that was above the water when the experiment started.

Extension

1. **Analyzing Data:** Antarctica and Greenland are both covered by ice sheets, also known as continental glaciers. The graphs "Land Ice in Antarctica" and "Land Ice in Greenland" show the change in mass of each in Gigatons (Gt) from 2002–2022. The gap in the graphs represents a time when there was no data collection taking place.

a. Which ice sheet has lost more mass over this 20-year period? Use evidence from the graph to support your answer. Why do you think that location has lost more ice mass?

Notes for the Facilitator: The Greenland ice sheet has lost approximately 5000 Gt, which is 2000 more Gt than the Antarctica ice sheet has lost. Learners' ideas about why this is occurring will vary, however, the main contributor to ice loss is Greenland has to do with the Arctic Ocean having warmer water than the Southern (Antarctic) Ocean. Warm water moderates the climate of the area, so the air temperatures in the Arctic are also warmer than in the Antarctic. Climate change has led to a faster increase in average temperatures in the Arctic than in the Antarctic.

b. Why do you think the lines have small peaks and valleys?

Notes for the Facilitator: These are the seasonal changes in the mass of the ice sheet, with valleys indicating warmer months where ice melts faster than it is added to the ice sheet, and peaks indicating colder months, where more ice is being added than is melting.

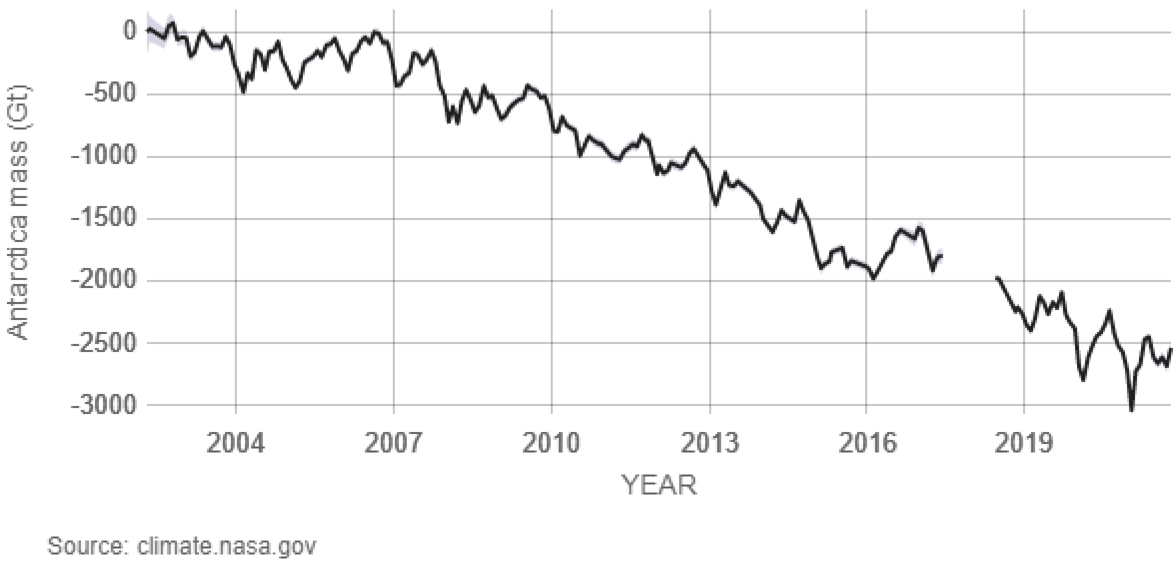
c. Predict what the graphs might look like during the period when data was not being collected. Why do you think this?

Notes for the Facilitator: Answers will vary but should describe the line as continuing the overall downward trend. The lines will be jagged, but the peaks and valleys for Greenland seem more regular and predictable than those of Antarctica.

d. Given these trends, predict how a graph of the number of icebergs around Greenland and Antarctica over time might look. Explain your answer.

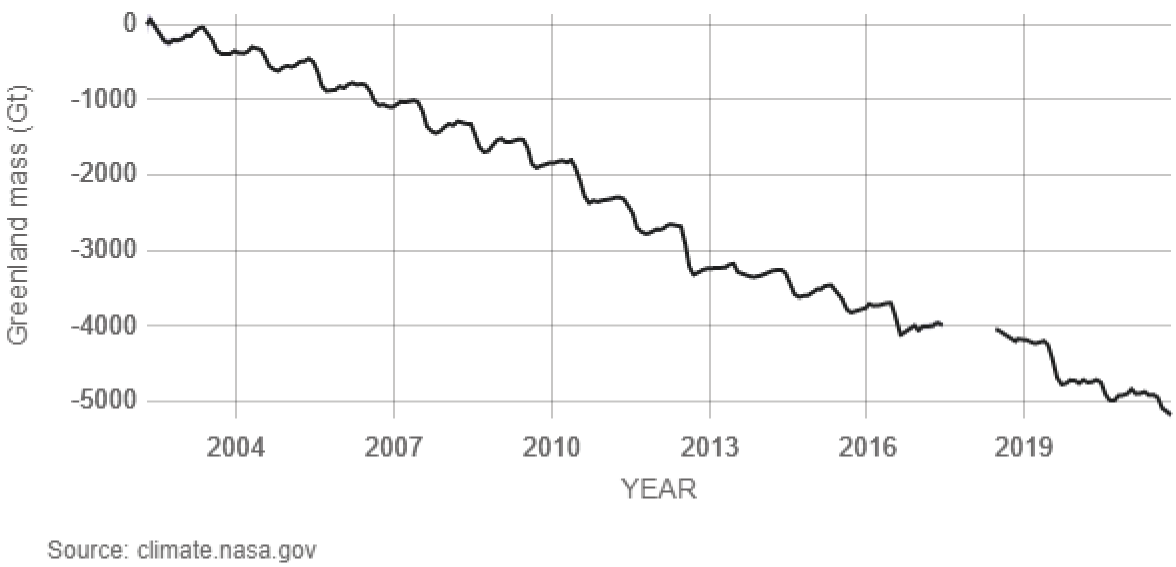
Notes for the Facilitator: There may be an increase in icebergs due to large pieces of each ice sheet breaking off. There would likely be more icebergs near Antarctica, as it is losing more mass than Greenland, which may be due to large pieces of ice breaking off and forming icebergs. Some learners may indicate that warming also leads to icebergs melting, which could affect their ability to predict the number of icebergs.

LAND ICE IN ANTARCTICA



Credit: NASA, https://climate.nasa.gov/vital-signs/ice-sheets/

LAND ICE IN GREENLAND



Credit: NASA, https://climate.nasa.gov/vital-signs/ice-sheets/

SUSTAINABLE DEVELOPMENT GOALS

AGI american geosciences institute
connecting earth, science, and people

INVESTIGATION 5B: MITIGATION OF COASTAL FLOODING

Facilitator Background

Connection to SDG 13: Indicator 13.1.3 encourages an increase in the number of places that "adopt and implement local disaster risk reduction strategies" (**https://sdgs.un.org/goals/goal13**). Many countries have major cities along their coastlines, which means that finding ways to make coastal flooding less severe—that is, coastal flooding *mitigation*—is a *risk-reduction strategy* that communities can assess and consider for funding. This Investigation has learners complete a case-study on coastal flooding in Texas to learn how coastlines could be impacted by rising sea levels. This case study process can be applied to other communities of interest to the learners.

Key Concepts: *mitigation, risk-reduction strategy*

Learning Outcome: Analyze data and maps on coastal flooding to understand the impact this environmental change will have on people in the future.

Connect to the ESD Kit Project: Design a Resilient City: Learners can use this Investigation to inform them of where they want their city to be located. The Consider questions are particularly important for understanding possible mitigation strategies if they decide to design or modify a city along a coastline.

PACING GUIDE

PREPARATION

10 minutes making copies of graphs and maps

WHAT TO DO

30 minutes for the Investigation

Materials

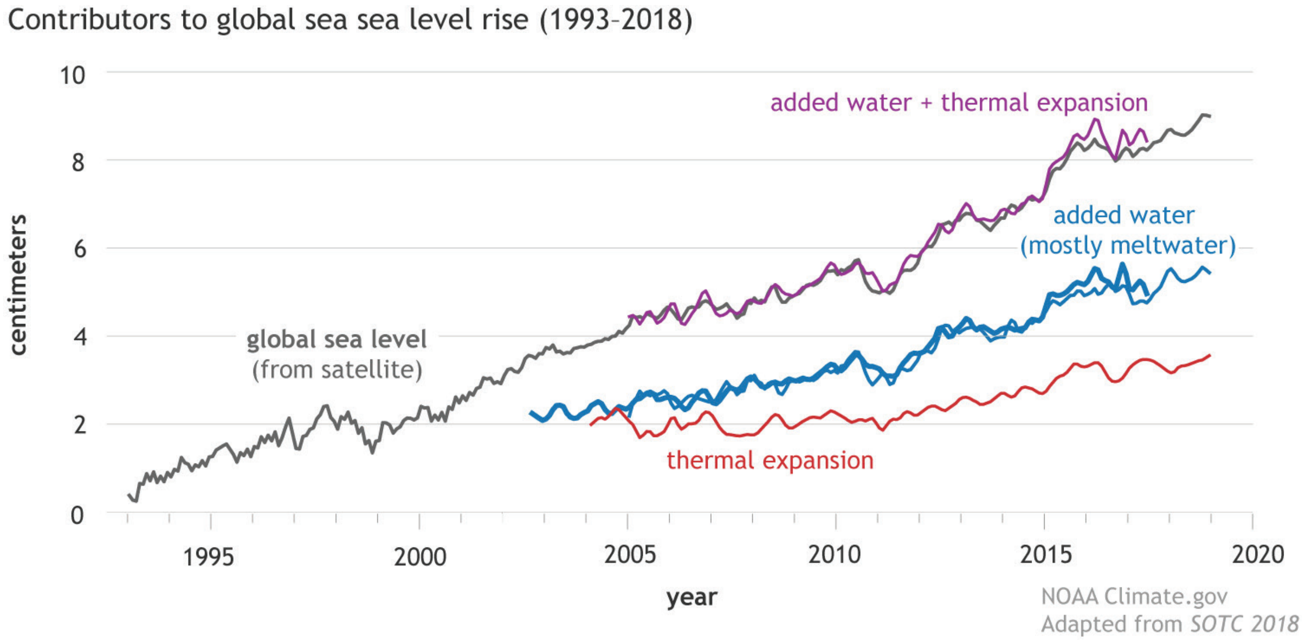
Per group:

- graphs
- maps
- calculator (optional)

What to Do

1. Examine the graph, "Contributors to global sea level rise (1993–2018)". It shows how sea level has changed due to thermal expansion and meltwater. Which factor had the greatest contribution to sea level rise? How can you tell?

Notes for the Facilitator: Meltwater has contributed more to sea level rise than thermal expansion. The line for meltwater has a steeper slope and so a greater increase (2 cm to almost 6 cm) in the same time that thermal expansion has contributed less than 2 cm to sea level rise.



Credit: NOAA

2. Examine the graph, "Global Sea Level is Projected to Rise". It shows projected sea level rise based on different scenarios.

a. What do you think the striped areas around each line on the graph represent? What information do these areas give you that the line alone does not?

Notes for the Facilitator: The line is the average estimate for sea level rise given each scenario, whereas the colored striped areas show the maximal and minimal limits of the expected change. What is expected to occur will fall somewhere in this zone.

b. Approximately how much is sea level expected to rise if carbon dioxide emissions are eliminated?

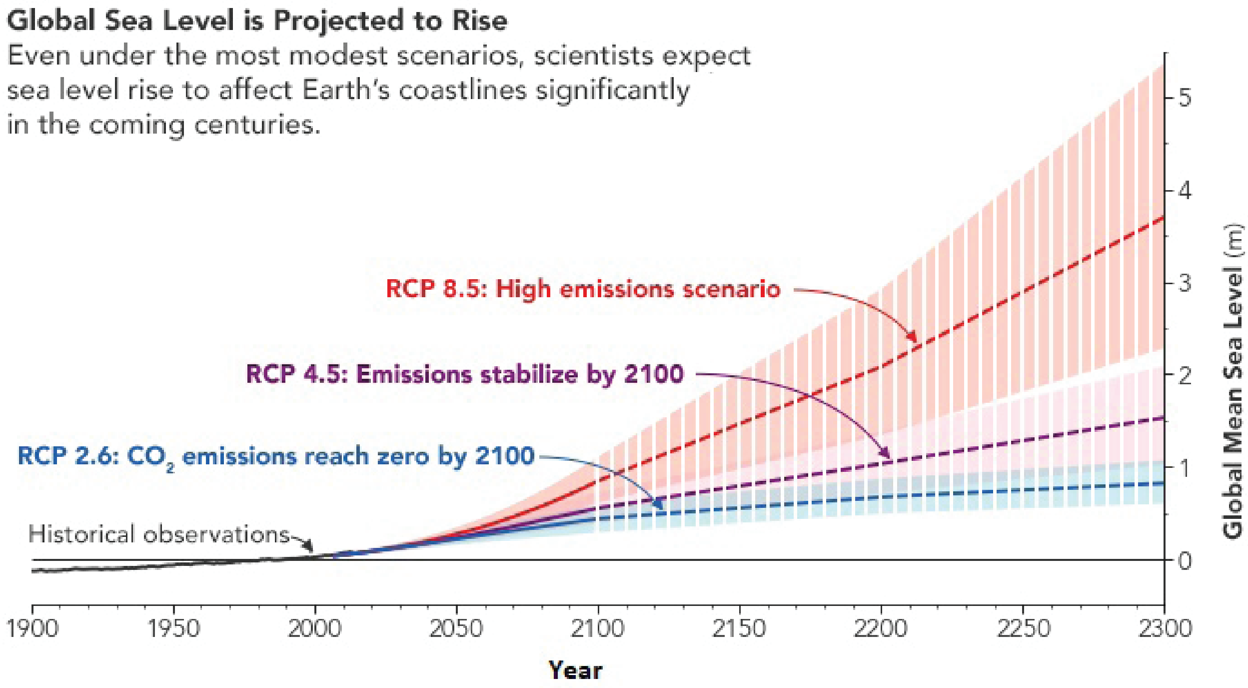
Notes for the Facilitator: Between 0.6 m and 1.1 m. The average estimate is just less than 1 m.

c. Approximately how much is sea level expected to rise if carbon dioxide emissions are reduced?

Notes for the Facilitator: Between 1.1 m and 2.0 m. The average prediction is approximately 1.5 m.

d. Approximately how much is sea level expected to rise if carbon dioxide emissions remain high?

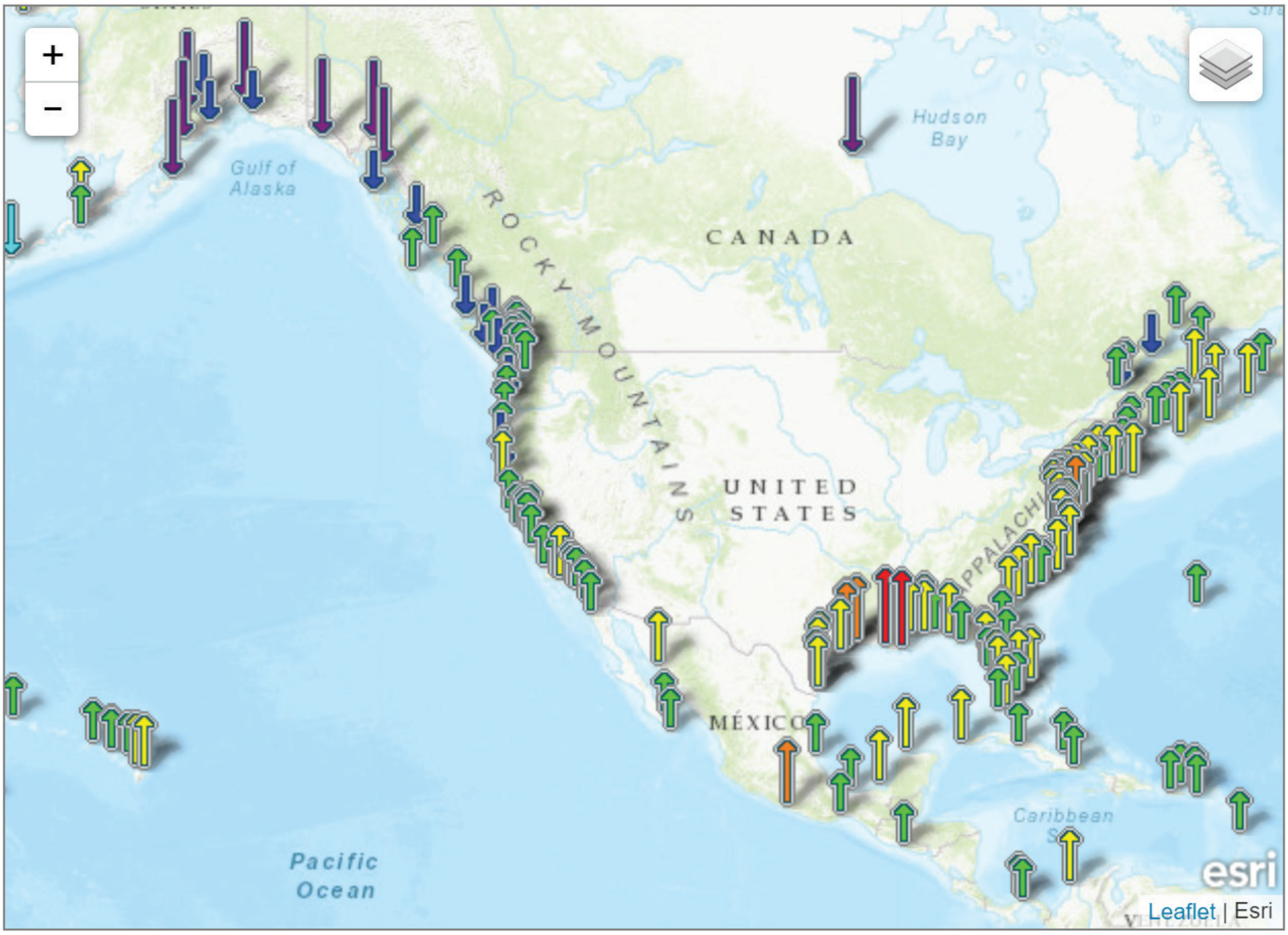
Notes for the Facilitator: Between 2.3 m and 5.3 m. The average prediction is approximately 3.8 m.



Credit: Modified from NOAA. For a description of RCP, see the California Energy Commission.

3. The map shows how the coastline of the United States is being affected by sea level rise. These measurements were taken using a tide gauge since 1992. The arrows indicate the amount of change that has occurred in the tide gauge readings. Which coast is more negatively affected: East or West? How can you tell?

Notes for the Facilitator: The east coast is more negatively affected because all but one arrow is pointing up, indicating higher tide levels. Higher tide levels are likely to lead to more flooding. The arrows on the east coast are also mostly yellow, which represents 3–6 mm of change, versus the many green arrows on the west coast, which represents 0–3 mm of change. The east coast also has some orange and red arrows, indicating even more of an increase in sea level rise (over 6 mm). The large downward arrows in Alaska and Hudson Bay are due to post-glacial rebound, so the crust is actually rising in some areas more quickly that sea level is rising. Similar rebound is seen on other continents that have been recently (geologically speaking) deglaciated.

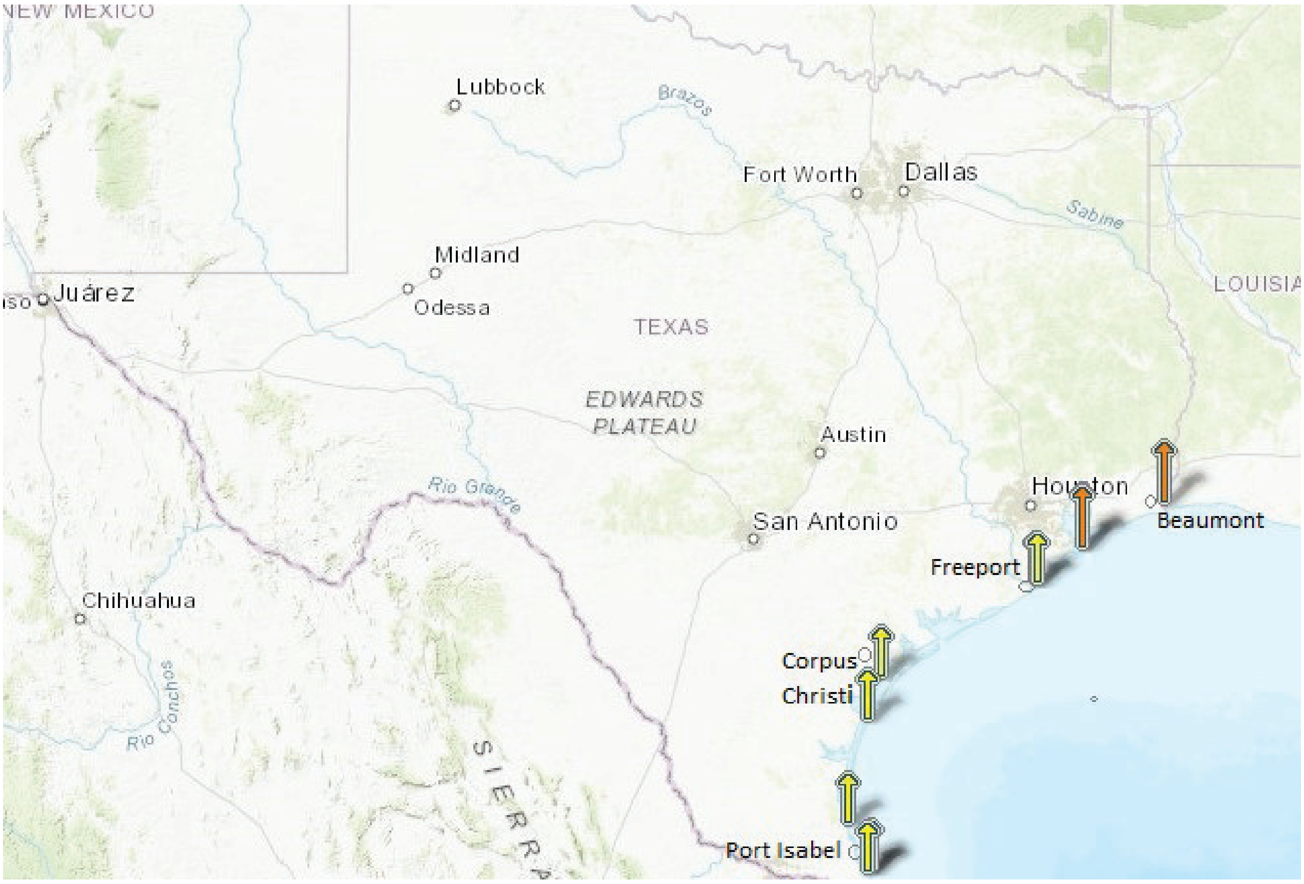


Credit: NOAA

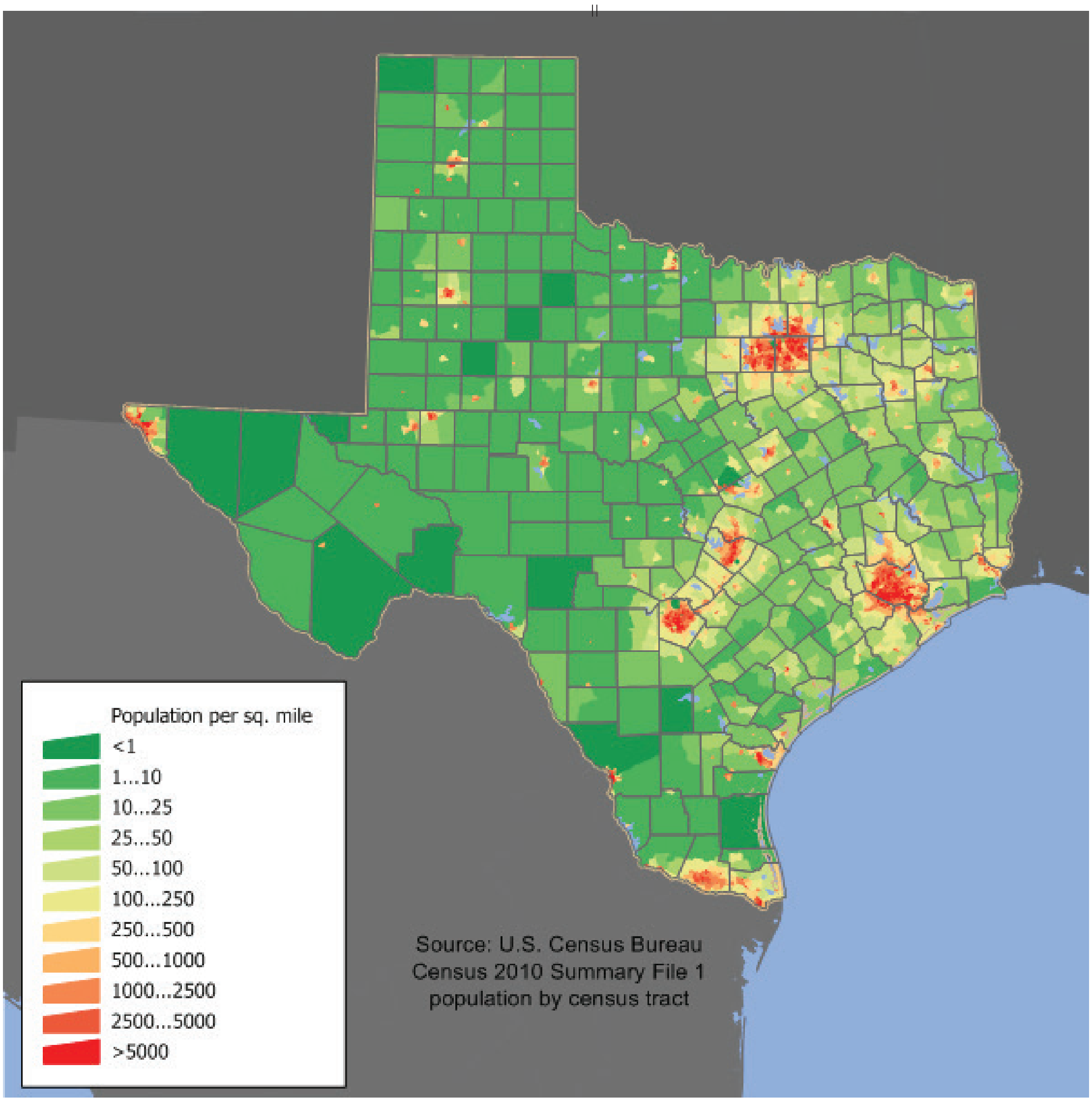
Notes for the Facilitator: If possible, have learners access the interactive version of this map at: **https://tidesandcurrents.noaa.gov/sltrends/**

4. Zooming in on the state of Texas, we see predicted sea level rise. The second map shows the population of Texas. Are there heavily populated areas that will be affected by coastal flooding as sea level rises? What effects will coastal flooding have on the more heavily populated areas?

Notes for the Facilitator: Houston has the largest population of any of the cities that will be affected. Houston has an orange arrow, indicating that it already has a 6 mm to 9 mm increase in tide height. The other coastal cities shown on this map (Beaumont, Corpus Christi, Freeport, and Port Isabel) are not as populated as Houston, but still have relatively dense populations, meaning that millions of people in Texas will be (or already are) affected by coastal flooding due to sea level rise.



Credit: Modified from NOAA



Credit: Creative Commons, https://commons.wikimedia.org/wiki/File:Texas_population_map.png

5. Compare the following maps, "Current Sea Level" and "Predicted Sea Level if Carbon Dioxide Emissions are Reduced". Current water levels are shown in blue, while predicted moderate sea level rise (1.5 m (5 ft)) is shown in light blue.

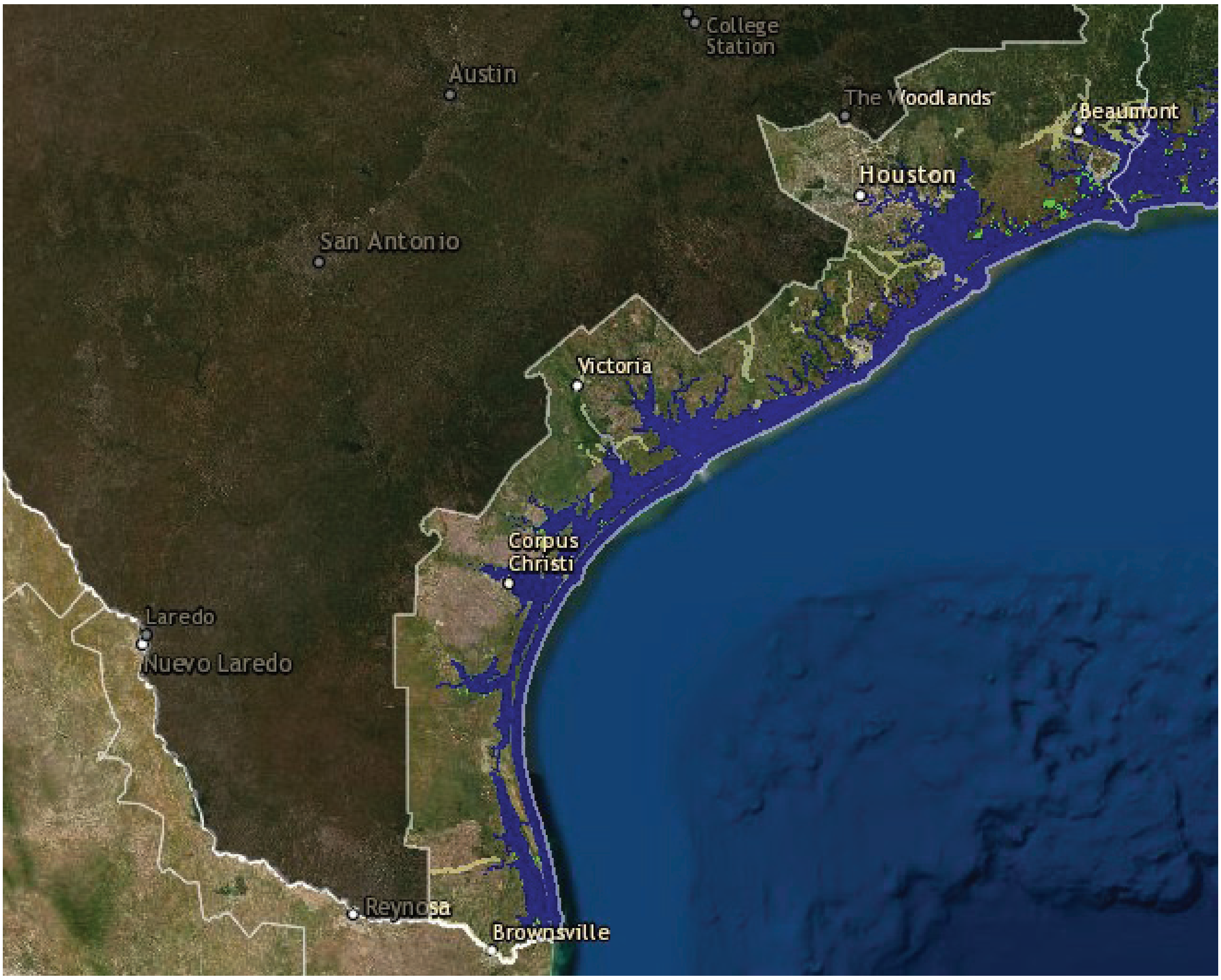
a. What areas are currently most affected by a rise in sea level?

Notes for the Facilitator: Beaumont is mostly covered by water with a moderate sea level rise. Many areas of Houston would also be under water. Almost the entire coastline between Corpus Christi and Brownsville is also under water.

b. Are these heavily populated areas? How might sea level rise affect heavily populated areas versus smaller towns or rural areas?

Notes for the Facilitator: Houston is the most heavily populated area on this coastline, although the other cities mentioned do also have relatively large populations. This may cause houses and other buildings to become flooded, so people and businesses may need to relocate. The areas between these coastal cities are sparsely populated, so coastal flooding would have less impact on the houses in those areas, but may impact ecosystems, farms, or roads located there.

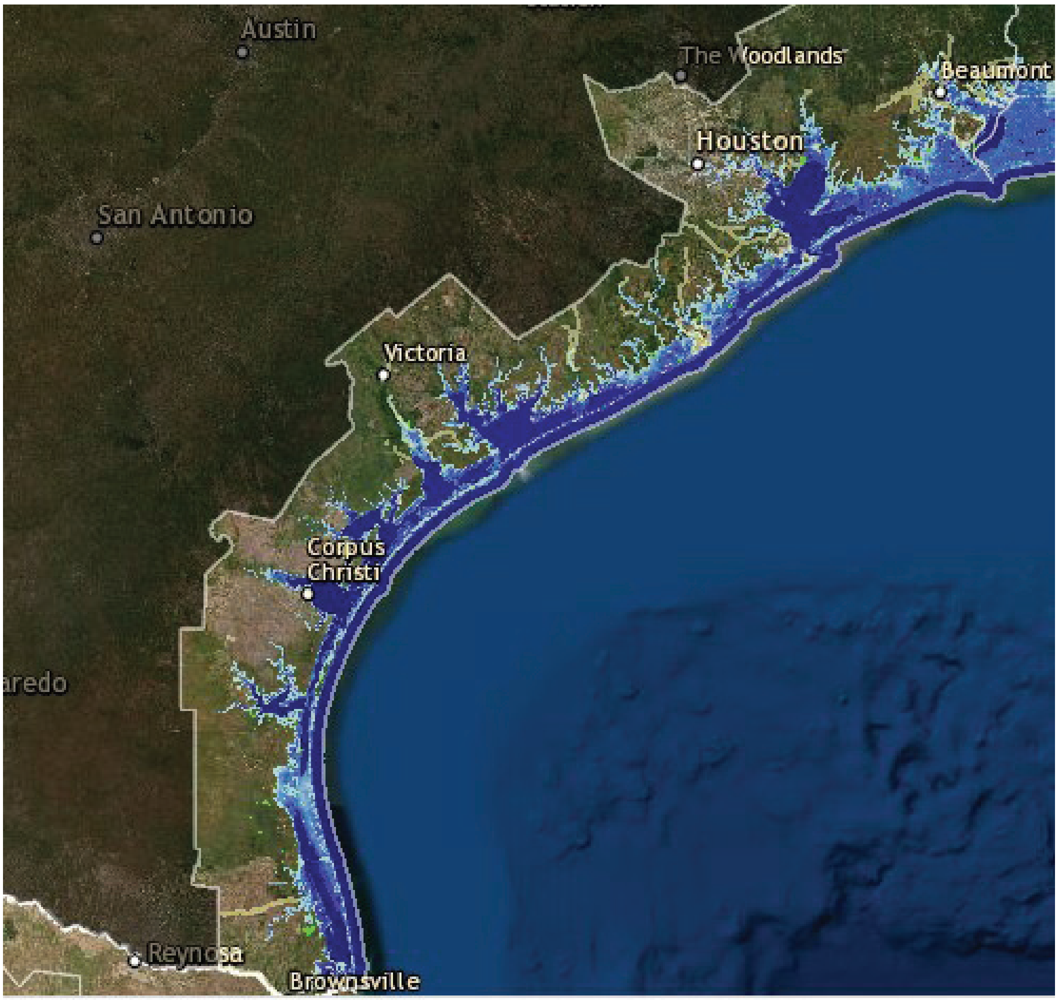
CURRENT SEA LEVEL



Credit: NOAA

Notes for the Facilitator: If possible, have learners view the interactive map at: https://coast.noaa.gov/slr/#/layer/slr/2/-10677376.802661583/3281322.116861207/7/satellite/none/0.8/2050/interHigh/midAccretion

PREDICTED SEA LEVEL IF CARBON DIOXIDE EMISSIONS ARE REDUCED, ESTIMATED +1.5M ABOVE CURRENT SEA LEVEL



Credit: NOAA

Consider

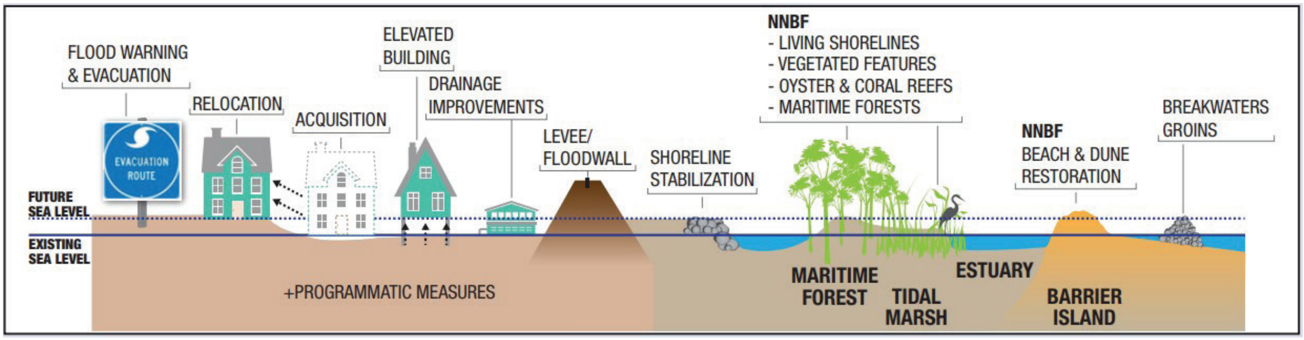
1. Cities in Texas have focused on Structural Measures to adapt to more frequent coastal flooding. This includes acquisition and relocation, as well as elevated dwellings and drainage improvement, shown in the image below.

   a. Why are these considered adaptation strategies rather than mitigation strategies?

Notes for the Facilitator: Adaptation strategies are changes people make to deal with environmental changes that have already occurred or a currently happening. In the case of flooding, these strategies are ways to work around flooding rather than trying to prevent flooding or further climate change.

   b. Would the other strategies shown in the image be adaptations or mitigation strategies? Explain why you think so.

Notes for the Facilitator: Shoreline stabilization is an adaptation strategy for preventing further coastal erosion due to flooding and storms; it prevents further damage, not the actual flooding. Most of the more natural structures or environments (even though constructed by humans), such as the maritime forest, tidal marsh, and estuary are mitigation strategies. These prevent flooding by diverting water or preventing as much water from reaching the coastal cities.



Source: U.S. Army Corps of Engineers, North Atlantic Coast Comprehensive Study: Resilience Adaptation to Increasing Risk, January 2015, p. 7, https://www.nad.usace.army.mil/Portals/40/docs/NACCS/NACCS_main_report.pdf

Extensions

1. **Testing Variables:** In Investigation 4, you looked at some strategies for mitigating coastal storm damage.
   a. Which of those strategies could also be used for coastal flooding mitigation?
   b. If there is time, test some other strategies shown in the diagram above, or test your own ideas. Use the procedure from Investigation 4.
   c. Compare the results to determine which strategies seem most effective.
2. **Applying Concepts:** Use this site to analyze current or potential effects of sea level rise on an area near you: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool
3. Using *Scratch*®: *Scratch*® project on sea level rise: https://scratch.mit.edu/projects/585163046/
   It uses data from climate.gov; learners can remix it and/or use the data for their own visual representation of sea-level rise.

ESD KIT:
IMPACTS OF CLIMATE CHANGE

Sustainable Development Goal 13: Climate Action

INVESTIGATION 6A1: ALBEDO

Facilitator Background

Connection to SDG 13: Target 13.3 is intended to "improve education, awareness-raising and human and institutional capacity on climate change mitigation" (**https://sdgs.un.org/goals/goal13**). Climate change *adaptation strategies* aim to curtail factors that contribute to global warming. One factor that contributes to the temperature of Earth's surface is albedo. The extent to which albedo affects atmospheric temperature is unclear, and studies are being conducted to determine the effect of albedo on the temperature of Earth's atmosphere. This Investigation focuses on defining albedo and its effect on a surface's temperature.

Key Concepts: *adaptation strategies*

Learning Outcome: Measure temperature change of different colored materials to describe the effect of albedo on heat absorption versus reflection.

Connect to the ESD Kit Project: Design a Resilient City: An understanding of albedo can inform learners about changes that can be made to cities so they have a less significant temperature rise during the day. Controlling temperature rise can decrease the need for energy, such as for air conditioning.

PACING GUIDE

PREPARATION

10 minutes setting up materials for groups
20 minutes familiarizing yourself with micro:bit, if completing Investigation 6A2

WHAT TO DO

5 minutes discussing the introduction material
20 minutes for Investigation 6A1
20 minutes for Investigation 6A2

Notes for the Facilitator: This Investigation has two parts. Investigation 6A1 is the standard procedure for testing the effect of albedo on the temperature of a surface. Investigation 6A2 is the optional Technology-Driven version of the same procedure and can be done either after familiarizing learners with or having learners complete Investigation 6A1.

Introduction

Albedo is a measurement of how much light is reflected off the surface of an object. A surface with a low albedo (near 0) means the surface absorbs light energy and reflects very little. A surface with a high albedo (near 1) means the surface absorbs very little or no light energy and instead reflects it. Color is the main factor in determining the albedo of a surface. This is different than an object's ability to store heat, which is determined by many factors.

Materials

Per group:

- 3 pieces of paper (white, black, and another color)
- foil
- 4 pieces of cardboard
- 4 alcohol bulb thermometers
- sunny area (or desk lamp)
- light meter
- timer
- tape (optional)

What to Do

1. Cut 15 cm (6 inch) squares of foil, white paper, black paper, and colored paper.
2. Cut four 15 cm (6 inch) squares of corrugated cardboard.
3. Place all four pieces of cardboard near each other in a sunny area (alternatively, you can position a lamp directly over them so that it is equidistant from the four setups).
4. Set a thermometer on each piece of cardboard so that the bulb rests in the middle of it.
    a. Be sure that the numbers on the thermometer are facing up so they can be read easily.
    b. You may need to use tape to hold the thermometer in place.
5. Place one of the squares of paper or foil on top of each piece of cardboard.
6. Take the initial temperature of each setup and start the timer.
7. Use the light meter to get a reading of how much light is being reflected by each paper. Hold the light meter 2 cm (1 in.) above the paper to take the reading. Be sure to avoid casting a shadow from the light meter onto the paper as you take the reading.
8. Take the temperature of each setup every 3 minutes for 15 minutes.

Notes for the Facilitator: If the temperature of some surfaces is changing quickly (e.g., due to there being bright sunlight), you may want learners to take more frequent measurements. Depending on the learners, you can also normalize the readings by pointing the light meter upwards and taking a reading of the incoming light (but not directly at the sun or room lights). Dividing the reflected value (R) from the surface being observed by the incoming light (I) gives the Albedo (A = R/I) and helps correct for changing light conditions.

Consider

1. Graph your results. Be sure to label the axes and provide a descriptive title for your graph.

Notes for the Facilitator: The graph should have 4 lines, one for each setup. There should be a key to tell which line is for which paper or foil (either different colored lines or different symbols used for the data points). The x-axis should be labeled "Time (minutes)." The y-axis should be labeled "Temperature (°C)."

2. Which setup warmed the fastest? The slowest? Why do you think this is?

Notes for the Facilitator: The black paper should heat up the fastest, since dark colors absorb more light. The absorbed light becomes heat, making the surface get warmer than lighter colors. The foil should heat slowest due to it reflecting the most light and not warming up much. The white and colored paper should heat at a rate somewhere between the black paper and the foil.

3. Why do you think we placed cardboard under the papers? How might the results have been affected if we set the papers directly on the ground?

Notes for the Facilitator: Without a thick backing providing some insulation, the temperature of the papers could be influenced by the surface underneath them, which could also be warmed due to absorbing light and heat, or from other factors such as nearby materials. The cardboard backing provides for similar conditions (controlled variable) for all four materials.

4. What other factors could affect the temperature of a material besides color?

Notes for the Facilitator: Answers will vary but could include texture, finish (e.g., glossy, matte), the material's ability to hold in heat, surface area (size), and how directly or for how long they are exposed to direct sunlight versus shade.

5. How might the albedo of materials on a building affect the temperature of the building's interior?

Notes for the Facilitator: Albedo is expressed on a scale of 0–1. A surface with 0 albedo (dark surfaces) does not reflect any light energy, while a surface with an albedo of 1 (light-colored surfaces) reflects all of the light energy that hits its surface. Materials that have a lower albedo (near 0) are heated by sunlight, so will be more likely to cause the building to heat up, especially if they also hold heat well. Materials that have a high albedo (near 1) do not get as warm and are not likely to heat up the interior of the building.

6. How might the albedo of surfaces on the Earth affect the temperature of the atmosphere?

Notes for the Facilitator: The surfaces of buildings can heat up more when they are darker; as a result, molecules in the air can absorb heat when they contact the hot surface. This can cause a rise in the heat energy of the air molecules and possibly in local atmospheric temperature.

Extensions

1. **Testing Variables:** Identify at least three outdoor surfaces for which you could safely test the effect of albedo on surface temperature. The surfaces need to be flat so that you can set an ice cube on each. Use the light meter to measure how much light each reflects. Make sure all three surfaces get the same amount of sunlight.

   a. Predict which surface would cause an ice cube to melt the fastest. Explain why you think this. Place ice cubes of the same size on each surface and time how long it takes each to melt. Analyze your data in terms of how much light each surface reflected versus how long it took for the ice cube to melt.

   b. If you have an infrared thermometer, take the temperatures of each surface before you test it. Alternatively, you can touch each surface to see if there is a noticeable difference in temperature.

2. **Analyzing Data:** Examine the map, "NPP LSA on 20221031" which shows global land surface albedo.

   a. What parts of the world have the highest albedo? Consider the type of environment in these locations. Discuss why the albedo in these places might higher than other places.

Notes for the Facilitator: Areas near the poles have the highest albedos, as indicated by the red on the map. The poles have a lot of ice and snow, which is white and reflects light. Surfaces that reflect a lot of light have the highest albedos. For a map that includes the albedo of oceans, see: **https://commons.wikimedia.org/wiki/File:Ceres_2004_clear_sky_albedo.png**.

   b. What parts of the world have the lowest albedo? Consider the type of environment in these locations. Discuss why the albedo in these places might be lower than other places.

Notes for the Facilitator: The lowest albedos are indicated by blues, which are mostly near or south of the equator. These habitats are mostly forests and grasslands. Since green plants absorb most of the sunlight that hits them, they have a low albedo.

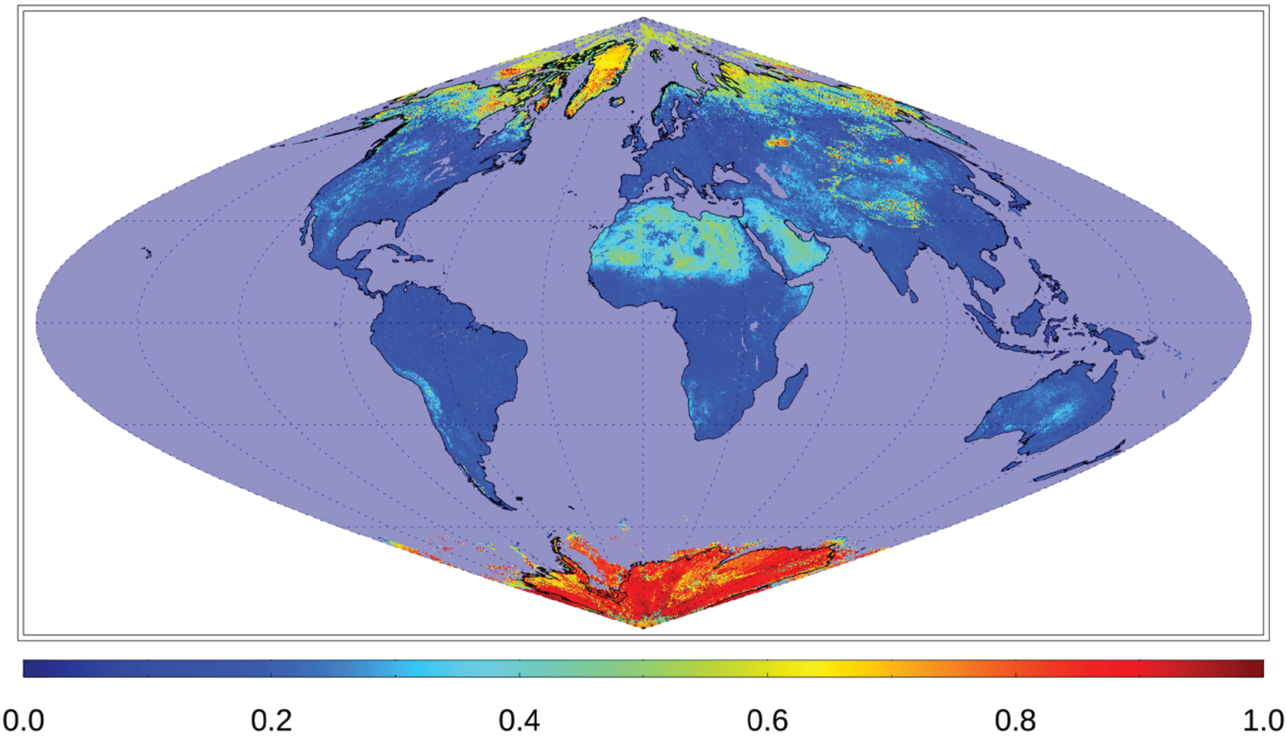
   c. Choose two areas for which there is no data. Predict the albedo for these areas. Explain your choices and your predictions.

Notes for the Facilitator: Answers will vary. Researching a map of the world's biomes (ecosystems) will help make predictions and explain answers, such as at: **https://en.wikipedia.org/wiki/Biome**

   d. The data to make this map was taken in February. Predict what areas might have a different albedo if the data were taken in July. Why do you think this?

Notes for the Facilitator: Northern Asia and North America may have less reds in July, since some snow and ice melts in their summer months. Antarctica may have even more reds in July, since this is a winter month in the Southern Hemisphere and more ice may form or more snow may fall.

NPP LSA on 20221031



Credit: NOAA, https://www.ospo.noaa.gov/Products/land/lsa/index.html

SUSTAINABLE DEVELOPMENT GOALS

AGI american geosciences institute
connecting earth, science, and people

INVESTIGATION 6A2: LOGGING TEMPERATURE AUTOMATICALLY USING A MICRO:BIT

Notes for the Facilitator: In Investigation 6A1, thermometers were used to explore how the color of a material affects its temperature. If you have not done that Investigation, you should review it with learners before going ahead with this one so you will have background information about albedo.

In this Investigation, a micro:bit microcontroller with a temperature sensor is used instead of a thermometer. The data will be recorded automatically and may be used to create graphs and other visualizations. Learners can test different colors of paper, or different groups can each test a color and share their data with other groups. It is important that you do not test foil on the micro:bit, since the foil conducts electricity and may cause short-circuiting that could damage the micro:bit.

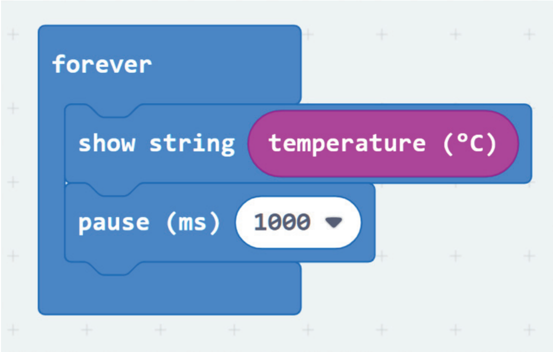
Materials

Per group:

- 3 pieces of paper (white, black, and another color)
- 3 pieces of cardboard
- 1 micro:bit V2 (some other micro:bits do not support data logging)
- 1 3 V battery pack for the micro:bit
- laptop or computer to program the micro:bit (can be shared by groups)
- sunny area (or desk lamp)
- light meter
- timer
- tape (optional)

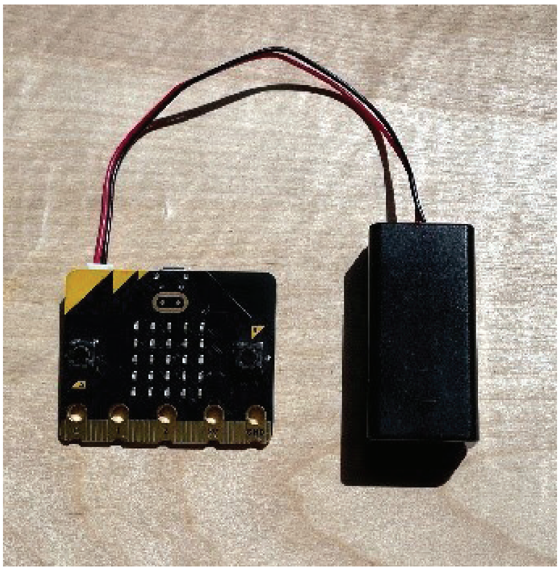
What to Do

1. The micro:bit has a temperature sensor built in. Before setting up the Investigation, the micro:bit needs a program to collect temperature data. Go to the MakeCode site: https://makecode.microbit.org/
   a. Start with a short sample program to test the micro:bit. Write this code in MakeCode. Connect the micro:bit to the computer using a USB cable to download the program.



Credit: MakeCode, https://makecode.microbit.org/

- Attach a 3 V battery pack so that you can disconnect the micro:bit from your computer while still allowing the program to continue to run.



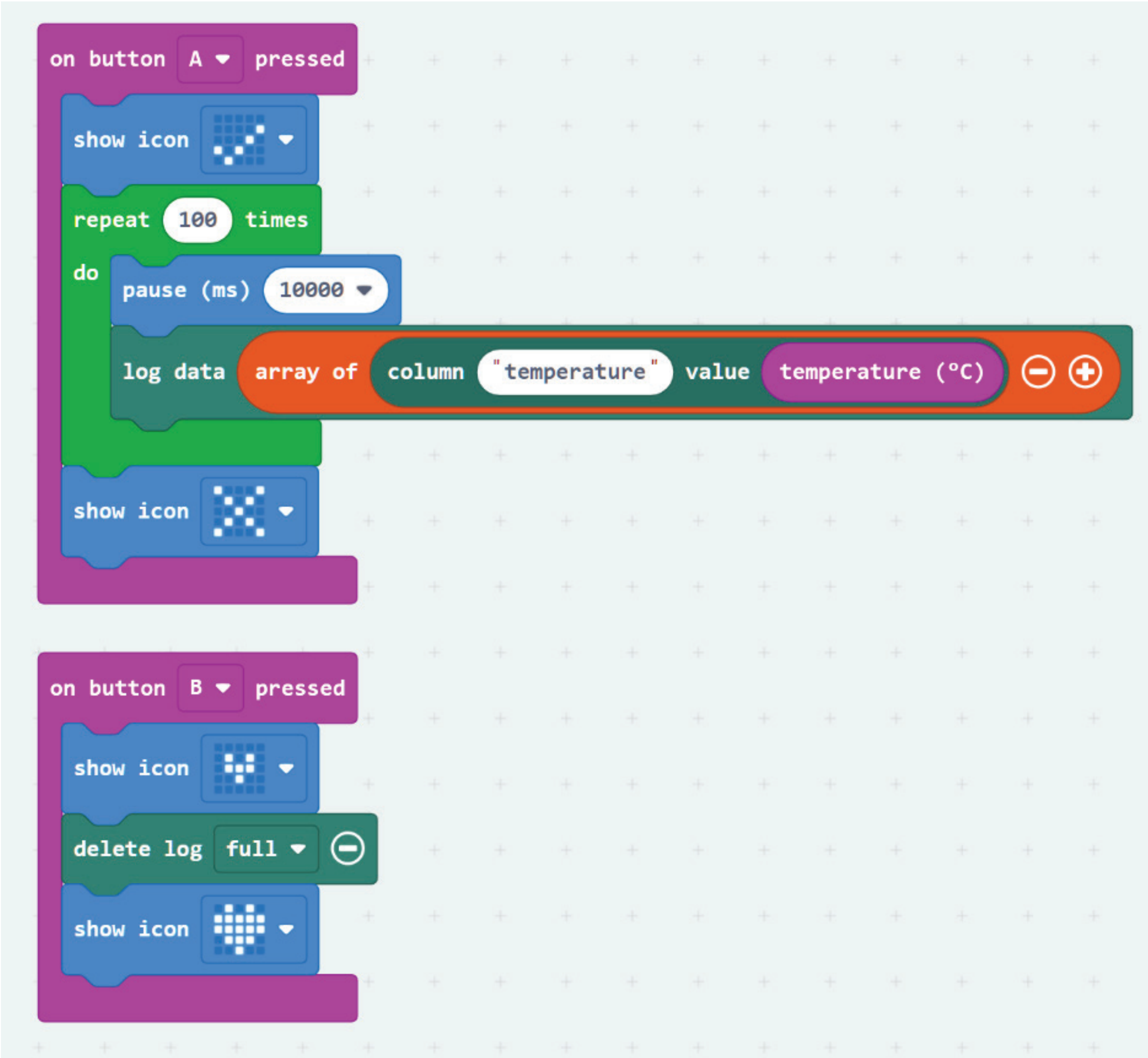
Credit: Logo Foundation

- The temperature of the room will display on the LED screen.
- The temperature being measured will most likely be a two-digit number, which cannot fit on the micro:bit screen. Instead, the digits scroll by one at a time.
- Where could you place the micro:bit to get different temperature readings? Predict how the temperature reading would change for each of these locations. Test some locations and compare the results to your predictions. Be careful not to place the micro:bit anywhere it could get wet.

b. To log temperature data, the micro:bit will need a more detailed MakeCode program. Access the program the micro:bit needs to log temperature data: **https://makecode.microbit.org/_C89gV5V9YhEW**

Notes for the Facilitator: If learners are writing this code on their own, they will first need to download the "Datalogger" extension. In the menu on MakeCode editor, choose "Extensions" and search for "Datalogger".

- This program is set to record data every 10 seconds (10,000 milliseconds). You can lengthen or shorten this interval by changing the number in the "pause(ms)" block.
- The program records 100 data points. You can increase or decrease this by changing the number in the "repeat __times" block
- The program also includes code to delete the data log from the micro:bit. If you don't do this before logging data, new data will be added to any data that is already on the micro:bit.



Credit: MakeCode, https://makecode.microbit.org/

c. Download the program to the micro:bit. Disconnect the micro:bit from the computer.

d. Plug the micro:bit into the 3 V battery pack.

e. On the micro:bit

- Press button B to delete any previous data on the micro:bit. You will see a small heart icon on the micro:bit display. After a moment, you will see a heart on the micro:bit display. This indicates that any old data has been deleted.
- Press button A on the micro:bit to start logging data
- A check icon appears to indicate that data logging has begun. An X icon will appear when data logging is completed. Cut 15 cm (6 inch) squares of white paper, black paper, and colored paper.

2. Cut one 15 cm (6 inch) square of corrugated cardboard.

3. Place the cardboard in a sunny area. Alternatively, you can place the cardboard under a lamp. The lamp should be approximately 15 cm (6 inch) above the cardboard.

4. Set a timer for the approximate total time the data logging will take.

    a. The code as written above will take about 17 minutes, which was calculated by multiplying 100 repeats by 10 seconds and dividing by 60.

    b. If you make changes to the number of repeats or the length of the pause, you will need to calculate how long the micro:bit will log data. Do this by multiplying the number of repeats by the duration of the pause and dividing by 60.

    c. The micro:bit displays an X when the data logging is completed, but you won't be able to see this until you lift the piece of paper. Note the time when the data logging begins and do not disturb the set up until enough time has passed that the data logging will have stopped. Be sure to not lift the paper until the timer has stopped.

5. Set the micro:bit on the piece of cardboard.

6. Start data logging on the micro:bit as described above and immediately place one of the squares of paper on top of the micro:bit.

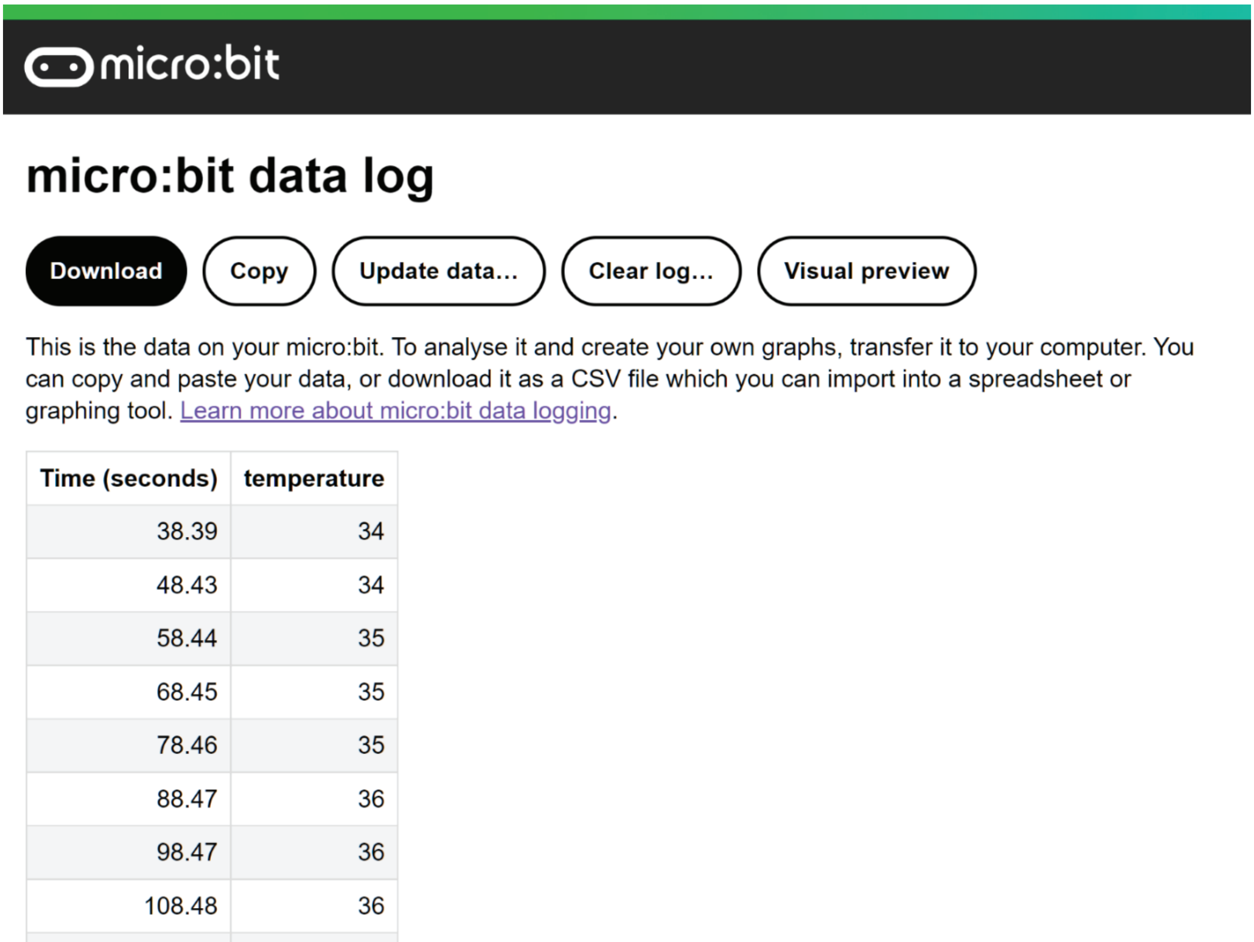
7. Use the light meter to get a reading of how much light is being reflected by each paper. Hold the light meter 2 cm (1 in.) above the paper to take the reading. Be sure to avoid casting a shadow from the light meter onto the paper as you take the reading.

Notes for the Facilitator: Learners can start reading through the Consider questions as data collection is taking place.

8. When the micro:bit has finished logging data, remove it from the sunny area or turn off the lamp.

9. Connect the micro:bit to the computer and open the file MY_DATA.HTM. You should see something like the chart below. You should download the data to your computer. It is best to do this as a .csv file, which can then be opened in Excel, *Scratch*®, or another application so that you can use it to create a graph or other visualization.

10. Make sure to delete the data log after downloading the data so that the micro:bit is ready to log the next batch of data.



micro:bit

micro:bit data log

Download | Copy | Update data... | Clear log... | Visual preview

This is the data on your micro:bit. To analyse it and create your own graphs, transfer it to your computer. You can copy and paste your data, or download it as a CSV file which you can import into a spreadsheet or graphing tool. Learn more about micro:bit data logging.

Time (seconds)	temperature
38.39	34
48.43	34
58.44	35
68.45	35
78.46	35
88.47	36
98.47	36
108.48	36

Credit: Logo Foundation

11. Allow the micro:bit to cool down in the shade for about ten minutes. Repeat the data logging with the black paper and colored paper or share data with other groups that have tested the other papers.

Consider

Notes for the Facilitator: If learners did not complete Investigation 6A1, they can also complete the Consider questions 2–6 from that Investigation.

1. Graph your results. Be sure to label the axes and provide a descriptive title for your graph.

Notes for the Facilitator: The graph should have 4 lines, one for each setup. There should be a key to tell which line is for which paper or foil (either different colored lines or different symbols used for the data points). The x-axis should be labeled “Time (minutes).” The y-axis should be labeled “Temperature (^{o}C).”

2. In Investigation 6A1, temperature was recorded every 3 minutes, while the micro:bit logged data every 10seconds.

a. If you completed both Investigations 6A1 and 6A2, did you see the same temperature trend? Describe them.

b. If you did not complete both Investigations, describe the temperature trend from the micro:bit data. Would you expect to see the same trends if the data was instead taken with a thermometer? Why or why not?

Notes for the Facilitator: Learners should observe the same trend as occurs using the thermometers. The white paper should have the lowest temperature. The black paper should be the hottest. The colored paper will have a temperature between that of the white and black papers.

c. What is one benefit of recording data more frequently?

Notes for the Facilitator: More frequent data points allow for a more complete picture of the trend of change over time. Less interpolation will be needed between data points.

d. What is one benefit of logging data automatically?

Notes for the Facilitator: Answers may vary but can include: less work, more reliable readings, and even time intervals between readings.

3. Consider how atmospheric temperature is monitored on Earth.

a. Why do you think we monitor Earth's temperature?

Notes for the Facilitator: Answers will vary but may include: to monitor changes, to keep a record so we know when variations occur, and to explain Earth systems.

b. What technologies do you think scientists use to regularly monitor temperature on Earth?

Notes for the Facilitator: Answers may vary but can include: thermometers, weather balloons, and satellites.

c. How often and at how many locations do you think data should be taken to get an accurate picture of Earth's average temperature?

Notes for the Facilitator: Answers will vary. More frequent data logging at more locations will get the most accurate data to calculate Earth's average temperature.

SUSTAINABLE DEVELOPMENT GOALS

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INVESTIGATION 6B: ALBEDO ENHANCEMENT

Facilitator Background

Connection to SDG 13: Target 13.2 aims to "integrate *climate change measures* into... planning" (**https://sdgs.un.org/goals/goal13**). Many countries have policies for urban planning in order to minimize the impact of development on the environment. Environmental urban planners have the role of assessing and minimizing the effect of construction projects on the environment. This Investigation looks at the assessment role of an environmental urban planner by comparing the albedo of natural surfaces to those of common construction materials. Consideration is then given to what changes can be made in construction practices to reduce the effect cities have on climate change.

Key Concepts: *climate change measures*

Learning Outcome: Test the albedo of natural surfaces and construction materials to understand the extent to which the overall albedo of cities differs from natural environments and how this could contribute to climate change.

Connect to the ESD Kit Project: Design a Resilient City: The effect albedo has could influence learners' choices about building materials used in their cities, as well as the size of the city (e.g., spreading the city out versus building vertically). A further consideration they may make when considering changes in albedo is where their city will be located and what types of environments they will disturb in order to construct their city.

PACING GUIDE

PREPARATION

10 minutes setting up materials for groups

WHAT TO DO

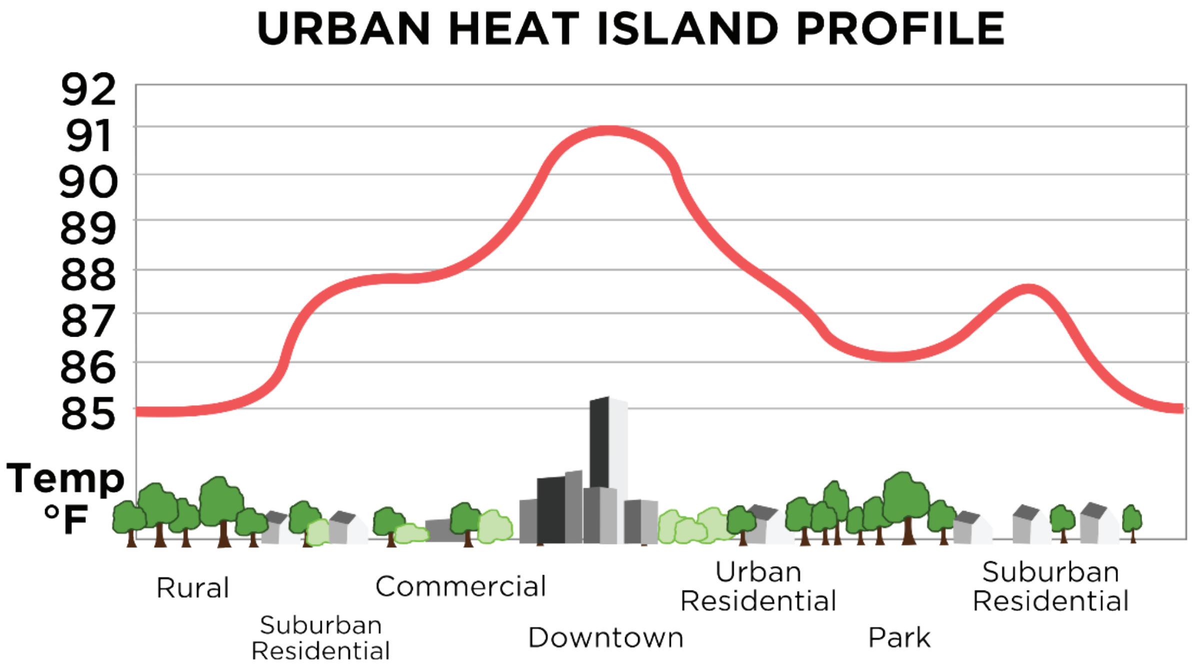
10 minutes discussing the introduction material

30 minutes for the Investigation

Introduction

The temperature of an area is affected by the climate and type of environment. The graph "Urban Heat Island Profile" shows different types of environments and how their local temperatures differ even though these environments are in the same climate.

Notes for the Facilitator: Have learners study the graph and make observations. Guide them not to focus on the exact temperatures, but on the relative differences. For example, a city may be as much several degrees warmer than a rural area in the same climate. Then, relate these temperature differences to albedo. What colors do they think of when they imagine city buildings and roads? Many construction materials are dark grey or black, which have low albedos and absorb light, which heats the materials and the surrounding air. Cities also generate heat as people use machines, automobiles, air conditioning, and other devices. The heat from the machines can raise the temperature of the surrounding air.



Credit: EPA, https://www.epa.gov/heatislands/learn-about-heat-islands

Approximately 3% of Earth's surface is covered by urban areas.* If urban areas are warmer, this may lead to an increase in Earth's average temperature, although this relationship has not been shown to occur.

* Liu, Zhifeng & He, Chunyang & Zhou, Yuyu & Wu, Jianguo. (2014). How much of the world's land has been urbanized, really? A hierarchical framework for avoiding confusion. Landscape Ecology. 29. 10.1007/s10980-014-0034-y.

Materials

Per group:

- pieces of construction material (brick, concrete, wood, roofing, siding)
- natural materials (sand, soil, grass, leaves)
- shallow tray or pan

- infrared thermometer
- desk lamp with an incandescent bulb (preferably 100 W)
- light meter
- cardboard (optional)
- sunny area (optional)

What to Do

Notes for the Facilitator: If there is not enough time for all learners to test all materials, have groups test different materials, then share their results. Alternatively, if it is a sunny day, these measurements can be taken outside, using different surfaces that are in direct sunlight.

1. Observe all the materials being tested. List them according to your prediction of how much light they will reflect. Rank them from lowest albedo (does not reflect much light) to highest albedo (reflects a lot of light).
2. Use the infrared thermometer to take the final temperature of the surface of each of the materials. Record these temperatures.
3. Place the lamp approximately 15 cm from the surface of one of the materials. Angle the lamp so it does not cast a shadow on the material.
4. Use the light meter to collect a reading of how much light the surface is reflecting.
   - **a.** Read the instructions for your specific light meter, but most will work well if used 2 cm from the surface of the material being tested.
   - **b.** Be sure to face the bulb of the light meter down toward the material being tested, not toward the lamp.
   - **c.** Repeat this for each material being tested.
   - **d.** Compare your readings to your predictions. Rearrange your list of materials as needed so they are in order from lowest albedo (lowest light level reflected, using the units given on your light meter) to highest albedo (most light reflected).
5. Turn off the lamp. Use the infrared thermometer to take the final temperature of the surface of each of the materials. Record these temperatures.
6. Predict what will happen to the temperature of each material when they are placed in the sun or under a lamp for 15 minutes.
7. Place all the materials in an area with direct sunlight. Alternatively, arrange the lamp so it is approximately 5 cm from the surface of one of the materials.
   - **a.** If using sand, soil, grass, or leaves, prepare a shallow pan of one of these materials.
   - **b.** If using a lamp, you will need to test each material separately. Make sure that all materials tested are on the same surface (carpet, desk, etc.) If this is not possible, place cardboard under all materials so they are all resting on the same type of surface.
8. After 15 minutes, use the infrared thermometer to take the temperature of the material. If using a lamp, turn it off, and measure the temperature at the spot of the material that was closest to the lamp. Record this temperature.

9. Consider the similarities and differences in temperature and light meter readings between the different materials. If your group didn't test all the materials, share your results with other groups and listen to their results.

Consider

1. Graph your results. Make sure to include a descriptive title and axis labels.

Notes for the Facilitator: Graphs will vary but should have two bars for each material; one for initial temperature and one for final temperature. The y-axis should be labeled "Temperature (˚C)," and the x-axis should be labeled "Materials," It is recommended that the materials are arranged in order from lowest albedo to highest albedo. An appropriate title would be something along the lines of "Temperature of Natural and Construction Materials Related to Albedo."

2. Compare the temperatures of the construction materials to the natural materials.

   a. Which material had the greatest temperature change? Why do you think this is?

Notes for the Facilitator: Answers will vary based on the materials used. A trend is expected that materials with lower albedos had a greater temperature increase.

   b. How would you expect each material to affect the surrounding air temperature?

Notes for the Facilitator: Air molecules contacting hotter surfaces could absorb some of the heat from those surfaces, resulting in the air around the surface becoming warmer. However, air molecules move constantly, so the more they are moving (e.g., on a breezy day), the farther they could travel from the surface once they are warmed, and so there might not be a significant rise in temperature right at the surface of the material.

   c. Use this information to explain the Urban Heat Island Profile.

Notes for the Facilitator: Construction materials tend to have a low albedo, so a city overall will have a low albedo. This can cause localized warming of the air, since the surfaces of the buildings and roads can transfer heat energy to the air molecules. Have learners refer to the graph in the Introduction if they need assistance.

   d. In what parts of the world would it be most beneficial for people to use building materials with low albedos?

Notes for the Facilitator: In colder climates, low albedo building materials can help to warm buildings so that less electricity (or other energy source) is used to heat the buildings.

Extensions

1. **Testing Variables:** Investigate the albedo of alternative construction materials or green infrastructure materials that have been developed for the purpose of reducing the effect of urban areas on the environment.

   a. What are some different types of alternative construction materials? How do you think they reduce the urban heat island effect of urban areas?

Notes for the Facilitator: Adding paint to a surface can change the albedo without having to alter the building materials used. Adding solar panels to a building allows for light to be absorbed before it even reaches the building materials. Green roofs can also raise the albedo of a building, while also taking in carbon dioxide from the air and reducing surface water runoff from the city. Additional green spaces added to a city also raise the city's albedo so it does not get as warm.

b. Explain other ways these materials could reduce a building's environmental impact.

Notes for the Facilitator: Raising the albedo of the exterior of a building causes it to warm less, which means the interior of the building warms less. If a building is in a warm climate where air conditioning is used frequently, having a high albedo could help keep the building cooler so that less electricity is used. Lowering the albedo of buildings in cold climates could allow for less electricity to be used to heat the building. Less electricity usage can help reduce greenhouse gas emissions, since most electricity is produced by burning fossil fuels.

ESD KIT:
IMPACTS OF CLIMATE CHANGE

Sustainable Development Goal 13: Climate Action

INVESTIGATION 7A: ASSESSING SOIL HEALTH

Facilitator Background

Connection to SDG 13: Target 13.1 states the importance of having a plan to "Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries" (**https://sdgs.un.org/goals/goal13**). Every country is reliant on healthy soil to grow crops. All soils have some level of ability to adapt to the effects of climate change, which is called *adaptive capacity*. This adaptive capacity includes the ability to store carbon, but soil can only do when it is healthy. This Investigation has learners study the properties of soil to assess its health. Connections are then made to the role of soils in the carbon cycle and its potential to act as a carbon sink which can reduce greenhouse gases in the atmosphere.

Key Concepts: *adaptive capacity*

Learning Outcome: Conduct soil tests to observe the components of soil and analyze the health of different soils.

Connect to the ESD Kit Project: Design a Resilient City: Understanding why soil health matters and how it affects the environment and crop growth can inform community planners in cities and other settings about how to maintain soil health. Learners can use information from this Investigation to consider how the city they design can reduce negative impacts on local soils.

PACING GUIDE

PREPARATION

10 minutes setting up step 4 (1 day in advance)

20 minutes setting up materials for groups

WHAT TO DO

10 minutes discussing the introduction material and Facilitator Demonstration

45 minutes for the Investigation

Introduction

Terrestrial ecosystems are diverse, and include: rain forests, deciduous forests, grasslands, deserts, tundras, and taigas (or boreal forests). Climate change impacts each of these ecosystems in different ways. These ecosystems rely on healthy soil to thrive, although each ecosystem has an ideal soil type.

The most common living organisms in the soil include bacteria, fungi, plants (i.e., their roots), and animals (e.g., worms, insects). All of these organisms exchange materials with the soil. Carbon, potassium, phosphorous, nitrogen, and water content are considered the most important components of soil with respect to the nutrients the soil provides. Carbon and nitrogen in the soil are often in organic forms, which are usable by organisms. Once organisms break down organic substances, they release inorganic gases such as carbon dioxide, methane, and nitrous oxide, which are transferred from the soil to the atmosphere in a process known as *flux*. These gases are greenhouse gases.

Changes or disturbances to the soil can result in changes in flux, causing soil to release more gases than it normally would, which can cause additional contributions to climate change. Many of these changes occur during farming when the soil is being worked. Undisturbed soil, however, can be described as a sink, or storage area, for carbon.

Maintaining the health of soil is an adaptive strategy since it tends to decrease greenhouse gas emissions from the soil. Improving the health of soil can be described as a climate change mitigation strategy, because soil that is remediated can help to remove excess carbon dioxide from the atmosphere.

Materials

For Facilitator Demonstration and Setup:

- soil sampler (corer)
- locally sourced soil
- pint-sized glass jar with a lid
- water

For Learner Investigation:

Per group:

- locally sourced soil (approximately 100 mL [1 cup] per group)
- bagged garden soil (approximately 100 mL [1 cup] per group)
- annual plant or grass grown in local soil with roots intact
- 1 small plastic bin or paper plate
- tap water
- distilled water
- vinegar
- baking soda
- teaspoon
- magnifying glass
- plastic cups [with a volume of ~200 mL (1 cup)]
- 4 plastic water bottles (or other clear, narrow containers)
- sand

- gravel
- trowel
- spray bottle filled with water
- bucket
- ruler
- 100 mL graduated cylinder
- soil testing kit (for nitrogen, phosphorous, and potassium, such as Luster Leaf Rapitest)
- pH test paper (if not included with the soil testing kit)
- safety goggles

Notes for the Facilitator: A healthy farming soil is typically dark due to containing organic matter and microorganisms, such as bacteria and fungi. It is suggested that you use local soil for the tests in this Investigation. However, it is useful to compare the results to soil that is sold for use with plants (i.e., garden soil, as potting mixes and bagged topsoil may lack some components of true soil). This will provide learners with a point of comparison as to whether their local soil is healthy or not. If possible, you can use multiple local soils as additional points of comparison. Some tests within this Investigation, such as tilth, rely on using naturally formed clumps of soil, called soil aggregates; since bagged soil does not form aggregates, it may not be possible to perform all of the tests using bagged soil.

Some procedures in this Investigation require soil that has been dried out, which may take up to three days. One procedure also requires that an annual plant (or patch of grass) be dug out of the ground so the roots can be observed; it is recommended that the Facilitator digs up one plant, and all learners will observe the same plant.

What to Do

Facilitator Demonstration:

1. Use a soil sampler to take a core of local soil.
    a. Sample several areas if possible.
    b. This should be done in advance of meeting with learners, but not so far in advance that the soil cores dry out.
2. Have learners make observations of the different layers (i.e., grain size, color, thickness). If more than one soil core was done, have learners compare the soil from different locations and make inferences about which they think is healthiest.

Learner Investigation:

Notes for the Facilitator: It is suggested that each of these short procedures be set up as stations. Learners can complete the stations in any order.

1. Tilth of the soil:
    a. Use a trowel to collect a large scoop of soil. Place it in a plastic bin or onto a paper plate where there is room to examine the sample.
    b. Use your hands to break apart the soil. Observe whether it is difficult or easy to break apart.
    c. Describe the relative shape and size of the pieces that break off.
    d. Take half a handful of soil and lightly mist it with water from a spray bottle (or faucet, but do not get the soil too wet).

e. Squeeze the soil into a tight ball. Gently set the ball in your bin or on your paper plate.

f. Observe whether the ball of soil falls apart or stays together as you set it down.

g. Gently poke the ball with your finger until it breaks apart. Observe whether this was easy or if it took some force to get the soil to break apart.

h. Repeat this procedure for each soil or compare your results with groups that tested different soils.

2. Test soil stability:

a. Healthy soil contains pockets of air. What do you think would happen if healthy soil is dropped in water?

b. Fill a plastic cup ¾ full of water.

c. Take a clump of soil that has been left out to dry and gently drop it into the cup of water. Start a timer.

Notes for the Facilitator: It is recommended that these dried pieces of soil are about the diameter of a thumbnail.

d. Once the soil settles to the bottom, make observations about what you see. When the soil stops changing, stop the timer.

e. Repeat this procedure for each soil or compare your results with groups that tested different soils.

3. Test the pH:

a. Place a spoonful of soil into a plastic cup.

b. Mix the soil with enough distilled water to make a mixture that is thinner than mud.

c. Let the mixture stand undisturbed for 5 minutes.

d. Hold the bag up and open it so you can get to the water at the top. To measure the pH, touch a test paper to the top of the liquid. Only touch a small portion of the strip to the liquid in so the color difference from the original color of the pH paper is still visible.

e. Repeat this procedure for each soil or compare your results with groups that tested different soils.

Notes for the Facilitator: As an alternative, if you purchased a soil test kit with a pH test, use the kit's instructions to test the pH. You can also test the pH of the solution in the jar of soil you prepared for the Soil Test Kit or Soil Particle Size procedures below.

4. Particle sizes:

a. Observe a sample of soil that has been prepared in a glass jar. The soil was mixed with water, and the sediment has been allowed to settle for the past 24 hours.

Notes for the Facilitator: To prepare the soil sample for this procedure, put about 250 mL (1 cup) of soil in a pint-sized glass jar (or similar container that has a lid). Add approximately one cup of water. Seal and shake the jar for one minute. Let sit undisturbed for 24 hours.

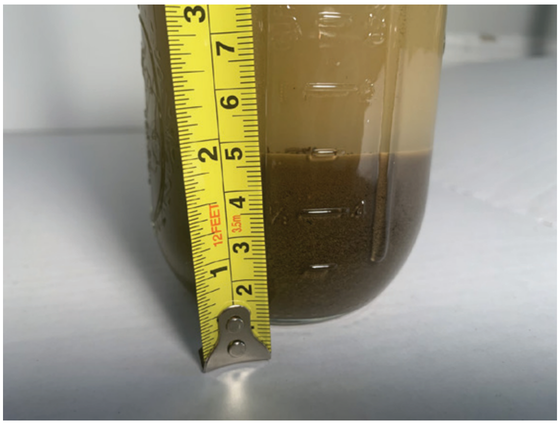
b. Without disturbing the jar, measure the height of the soil in the jar in centimeters.

Notes for the Facilitator: There should be distinctly colored layers, each containing a different sized sediment. If necessary, prompt learners to notice the layers.

c. Measure the height of each layer within the soil in millimeters.

d. Divide the height of each layer by the total height of the soil. Multiply by 100 to get what percentage of the soil each layer of sediment makes up.

Notes for the Facilitator: An example soil sample measured 4.8 cm. The large grains at the bottom of the jar are the sandy layer (seen below, this layer is approximately 3.9 cm, 81%). The second layer, which is a little lighter and has finer grains is clay (approximately 3.9 to 4.7 cm, 17%). The third layer is a light tan and is made of silt (approximately 4.7 to 4.8 cm, 2%).



Credit: L.C.Mossa

5. Soil test kit:

Notes for the Facilitator: Most soil kits come with their own instructions. The following instructions go with the Luster Leaf Rapitest. Most soil kits require that the soil sample used be taken from approximately 5–8 cm (2–3 in) below the surface. To prepare the soil: Break a small section of dried soil into small pieces. In a jar or clear water bottle, mix the soil sample with distilled water in a ratio of 1 part soil to 5 parts water (each test needs about 20 mL; use this to estimate how much solution to make). Shake or stir the soil and water for one minute. Let sit for 24 hours.

a. Use a pipette to fill the nitrogen testing box with the water your soil has been soaking in for 24 hours. Be sure to only take a sample of the water, not the soil.

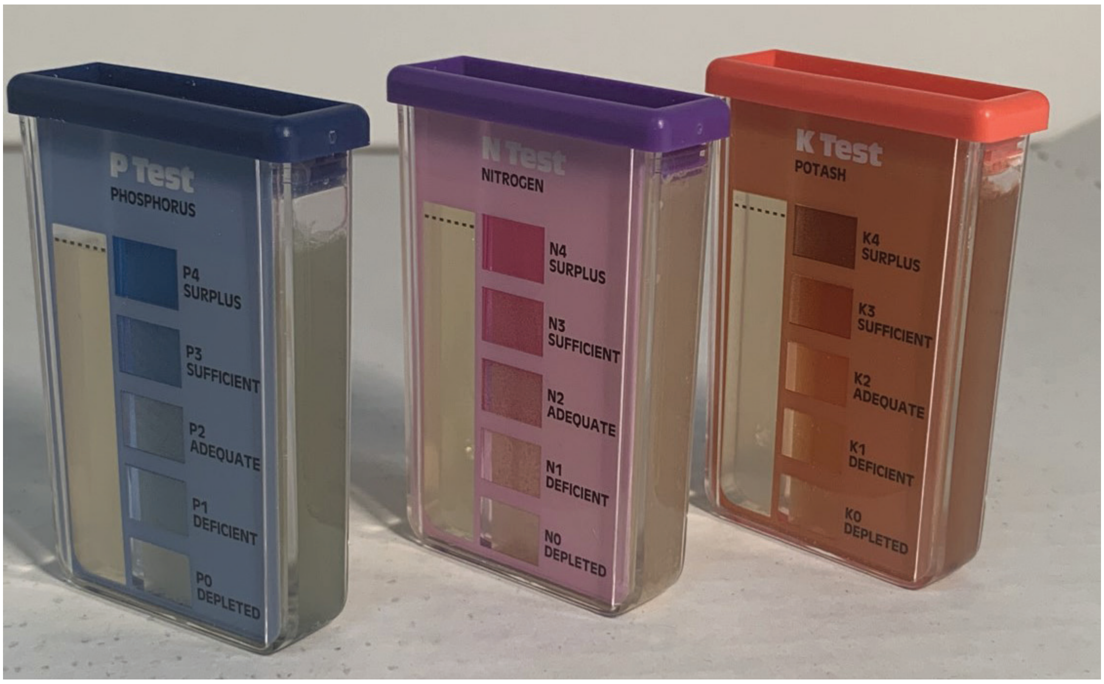
b. Break open a nitrogen testing capsule and pour the powder from it into the reference chamber.

c. Cap the nitrogen testing box and shake thoroughly.

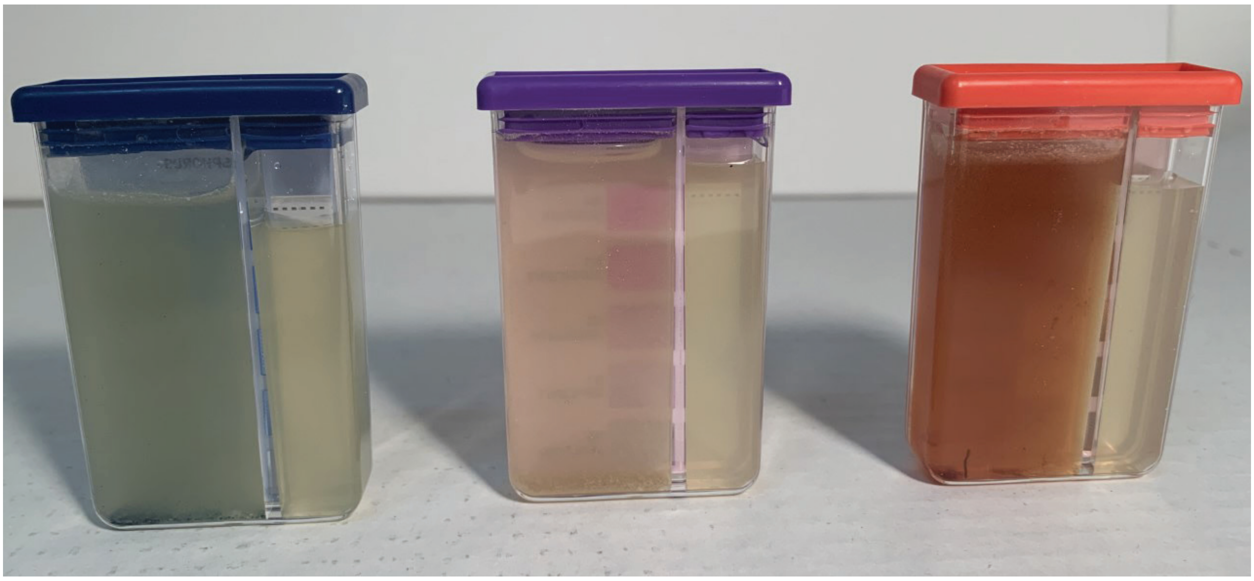
d. Let the solution sit for exactly 10 minutes, then match the color of the solution to the comparator chart. This is best done in natural, but not direct, light.

e. Repeat this procedure for both potassium and phosphorous, making sure to use the appropriate testing boxes and capsules.

f. Repeat this procedure for each soil or compare your results with groups that tested different soils.



Credit: L.C.Mossa



Credit: L.C.Mossa

6. Soil porosity:

a. Fill three plastic bottles ¾ full: one with sand, one with gravel, and one with soil from your area. Be sure each bottle is filled up to the same height.

b. Make observations of the size of the grains that make up each material and the pore space between the grains. Predict which material will hold the most water.

c. Use the graduated cylinder to fill a fourth plastic bottle with water. Record the total amount of water used to fill the bottle.

d. Slowly pour the water into the sand until water reaches the top of the sand. As you pour the water, make observations about how long it takes for water to go through the sand.

e. Use the graduated cylinder to measure how much water is left in the bottle. Subtract this from the initial amount of water to see how much water was used.

f. Refill the water bottle using the same method as before. Repeat the procedure with gravel, and then with your soil sample.

g. Repeat this procedure for each soil or compare your results with groups that tested different soils.

7. Root development:

a. Observe the roots of the annual plant that has been dug from the soil.

b. Make note of their color and texture, as well as anything else you notice about them.

Consider

1. Answer this set of questions for each soil that was tested: How easy was it to break apart the soil while doing the tilth and stability tests? During the tilth test, did it fall apart on its own or only after you pressed on it? How long did it take to break apart in water? Do you think this means that the soil is healthy or not healthy?

Notes for the Facilitator: After discussing their results, tell learners that healthy soils hold together well during a tilth test. They should not be too difficult to break apart, but they also should not readily fall apart on their own. During the stability test, a healthy soil should stay together for about a minute.

2. Many farms till their soil, meaning they use equipment to mix up the top layer of soil where they are going to plant crops. Tilled soil tends to fall apart easily when a tilth or stability test is run on it. Given what you now know about tilth testing, does tilling help make a soil healthier? Why or why not?

Notes for the Facilitator: Soils should not readily fall apart, so this would indicate tilling can lead to unhealthy soils. Tilling disrupts the life cycle of the bacteria and fungi that live in the soil. Tilling can also cause the soil to release excess gases, altering the nutrient content within the soil.

3. Compare the pH of the different soils tested. Are they acidic, neutral, or basic? Which do you think is ideal for plant growth? Why?

Notes for the Facilitator: Ideal soil pH is slightly acidic to neutral — between 6 and 7. Anything outside this range is typically not good for plant growth, although there are some exceptions of plants that do grow well in soils with pH outside of this range.

4. If you tested multiple local soil samples, which one seems to be the healthiest? Why do you think this?

Notes for the Facilitator: Bagged soil typically meets most, if not all, of the indicators for healthy soil because it is meant to aid plant growth. Any soils that test similarly to store-bought soil would be considered healthy. Soils with too much clay or silt do not hold organic matter well, so they are not as healthy, nor are soils that have a pH far from neutral, or do not contain enough minerals to support life.

5. Are there many farms near where you live? Use the soil conditions to explain why or why not.

Notes for the Facilitator: If possible, you can provide satellite images of your area for learners to see if there are nearby farms. Unhealthy soil can be treated, but it could be expensive to build farms where there is not enough healthy soil.

6. How could the soil in your area be improved?

Notes for the Facilitator: Answers will vary but can include the use of mulch, reducing the use of pesticides and processes that interrupt the soil ecosystem, such as tilling.

Extensions

1. **Testing Variables:** Healthy soils should allow for moderate drainage of water through the soil. With permission, go outside and test your soil's drainage:
    a. Remove both ends of a small (about 350 mL [12 oz.]) food can.
    b. Dig a hole about 2 cm deep in the ground that is big enough to be able to place the end of the can into the hole. Press down on the can enough to seal around the edge with soil, but no further.
    c. Fill the can halfway with water and time how long it takes to drain.
2. **Testing Variables:** With permission, go outside and dig a hole about the size of a coffee canister (about 10 cm [4 in.] wide and 14 cm [5.5 in.] deep). Observe the hole for 30 minutes and count the number of living organisms you see. What do you think the number and diversity of living organisms you observed tells you about the soil's health?
3. **Applying Concepts:** Unhealthy soils cannot support plant growth as well as healthy soils. However, plants can help make soils healthier, especially mosses. Think about when you have seen moss in nature. Where does it typically grow? What does it look like? Think about some of the properties of mosses. How do you think moss could help make soil healthier?

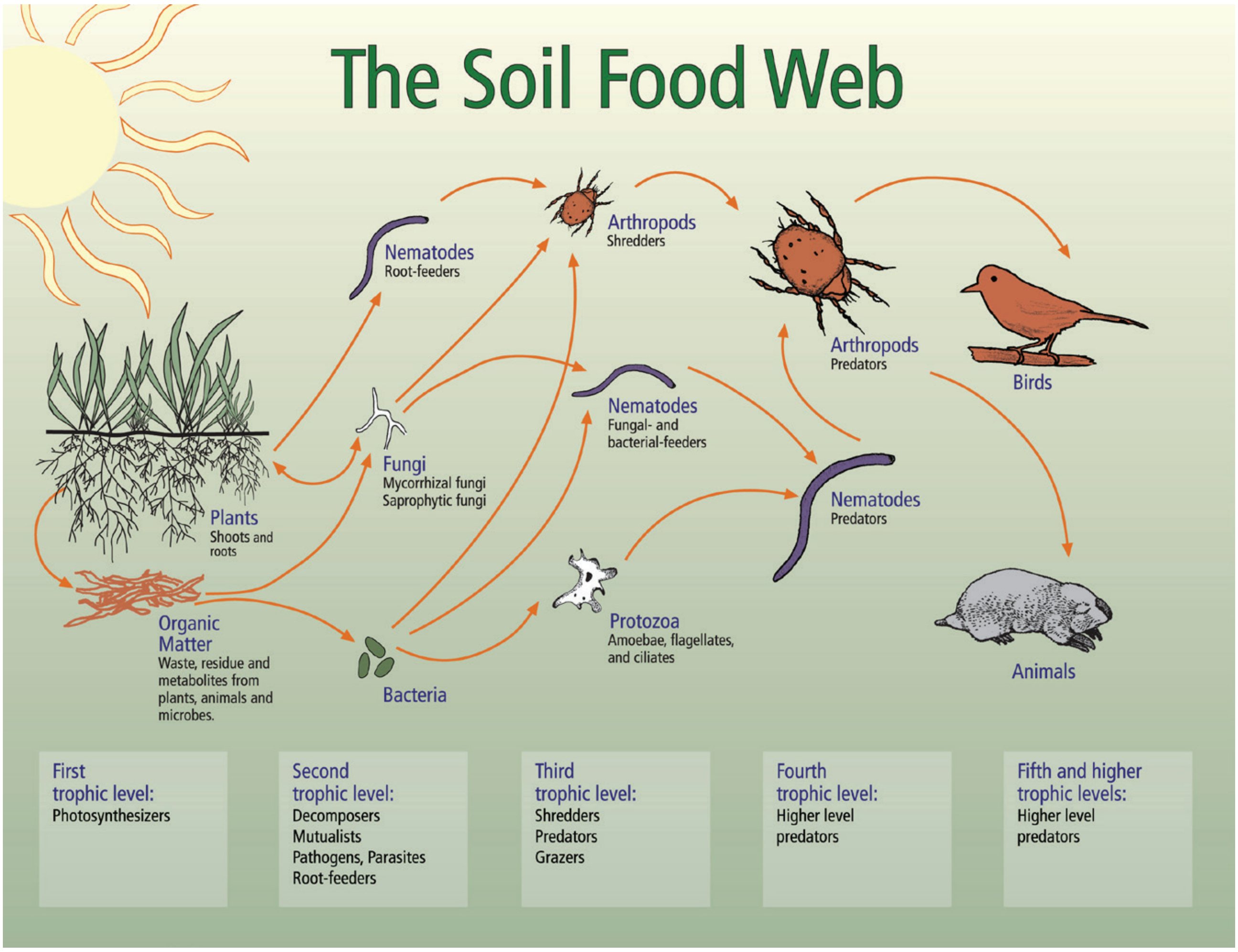
Notes for the Facilitator: Moss often grows on trees, logs, rocks, soil, and even on the walls of buildings. Moss does not grow very tall but is often found in clumps or patches. Moss needs to be short to access water because it lacks vascular (transport) tissue. The "roots" of moss act as anchors and can penetrate very hard surfaces and can break them down, which forms soil, but these modified roots often cannot take in water. Moss also covers bare areas, which helps in maintaining moisture in the soil.

4. **Applying Concepts:** One factor that determines soil health is its carbon content. The carbon in soil is typically in an organic form (unlike carbon dioxide, which is inorganic). Converting carbon dioxide to organic carbon and storing it in soil is called drawdown.
    a. Describe how the different types of organisms shown in the Soil Food Web Diagram can contribute to the carbon content of soils.

Notes for the Facilitator: All organisms give off waste that contains carbon, which adds more carbon to the soil. Decomposition of dead organisms also adds carbon to the soil. Some organisms dig through the soil, which exposes more of it to the air, allowing for greater surface area for soil to exchange gases with the air; this can increase the amount of carbon dioxide taken in by soil. Some organisms eat soil, which would reduce the carbon content.

5. Which level do you think contributes most to drawdown? Why do you think this?

Notes for the Facilitator: Bacteria and fungi that decompose dead organisms, or parts of organisms, such as fallen leaves, will return carbon to the soil.



Credit: https://www.mdpi.com/2571-8789/5/2/32/htm#

INVESTIGATION 7B: SUSTAINABLE FARMING PRACTICES

Facilitator Background

Connection to SDG 13: Indicator 13.2.2 is about integrating measures to reduce "total greenhouse gas emissions per year" (**https://sdgs.un.org/goals/goal13**). Soils can store large quantities of carbon, which means that they are considered a *carbon sink*. Even when soils lose carbon content, soils show *resilience* in that they can re-uptake carbon from the atmosphere rather quickly and through multiple means. Soils also display resilience by being able to restore their own health after they are disturbed. Many standard farming practices, such as tiling or planting the same crops yearly, disrupt soils and cause them to lose carbon to the atmosphere in the form of carbon dioxide. This contributes to greenhouse gas emissions, causing warming of the atmosphere. This Investigation looks at how sustainable farming practices can increase soil health by increasing the amount of carbon in the soil while also reducing atmospheric carbon dioxide levels.

Key Concepts: *carbon sink, resilience*

Learning Outcome: Analyze data that shows sustainable farming practices can increase soil health and make connections to atmospheric carbon dioxide levels.

Connect to the ESD Kit Project: Design a Resilient City: While farms are not a component of cities, they can be near enough to cities for the two areas to affect each other. During the project, students should consider how close farms will be to their city as well as ways in which their city might affect soil health on nearby farms.

PACING GUIDE

PREPARATION
10 minutes making copies of graphs

WHAT TO DO
10 minutes discussing the introduction material
30 minutes for the Investigation

Introduction

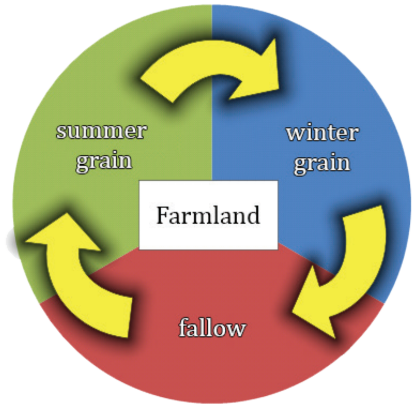
Notes for the Facilitator: It is suggested you start with a review of soil health, as seen in previous Investigations. In Investigation 7A, learners tested soil for nitrogen, potassium, and phosphorous. In Investigation 2A, learners observed soil respiration and that soil is a vital component of the carbon cycle.

Sustainable farming practices improve and maintain the quality of the soil. These practices also prevent organic carbon in the soil from being lost to the environment as inorganic carbon dioxide. Three common sustainable farming practices are: cover cropping, crop rotation, and no tillage.

Cover crops are plants grown in between the crops that are being grown for food. Their main purpose is to cover the soil, hence the name cover crops. There are many types of commonly used cover crops, such as grasses, alfalfa, and radishes, some of which can also be harvested as food, although the goal is soil coverage.

Credit: Creative Commons, **https://commons.wikimedia.org/wiki/File:Oats_cover_crop.jpg**

Crop rotation is a practice in which land use changes from year to year. For example, crops like corn require a lot of nitrogen, which they obtain from the soil. If corn is continuously planted in the same field, enough nitrogen could be removed from the soil to make it unhealthy, which means that less corn will grow in later years. A farmer can instead grow another crop on that same field in the next season or year instead of corn. Beans (legumes) are able to return nitrogen to the soil due to a symbiotic relationship they have with specific soil bacteria that can convert atmospheric nitrogen into organic nitrogen. If a field is alternated between growing corn and beans, the corn crops will be more successful due to having the nitrogen they need being replenished by the beans. Fields can also be left fallow, meaning that no crops are grown on it for a season or year, which allows the soil time to regain some nutrients.



Credit: Creative Commons, **https://commons.wikimedia.org/wiki/File:Crop_rotation_graphic_--_en.png**

Tilling is when soil is dug up and mixed. This is often considered a way to prepare soil for planting crops or can be done when mixing fertilizers into the soil. Tilling the top layer of soil can break down weeds but damages the natural soil structure. While there is a lot of regional variation, it is becoming more common for farmers to use no-till practices in conjunction with the other methods mentioned here as a way to keep their soils healthy.

Credit: Photo by Keith Weller, U.S. Department of Agriculture on **https://pixnio.com/**

Materials

Per group:

- copies of graphs from the Investigation

What to Do

Notes for the Facilitator: The graphs for steps 1 and 3 have units that learners may not be familiar with and may require some explanation. The unit for soil-carbon content in the first graph essentially is concentration of carbon (relative amount within a certain volume or area of soil). Flux, shown in the last three graphs is a rate of gases transferred from the soil to the atmosphere per area in one hour.

1. Two farms were studied in regard to the use of cover crops and their effect on the carbon-content of the soil. The results are displayed in the graph "The Effect of Cover Plants on Organic Carbon in the Soil".

    a. Compare the two farms when no cover crops were used. How does this compare to when cover crops are used? Use evidence from the graph to support your answer.

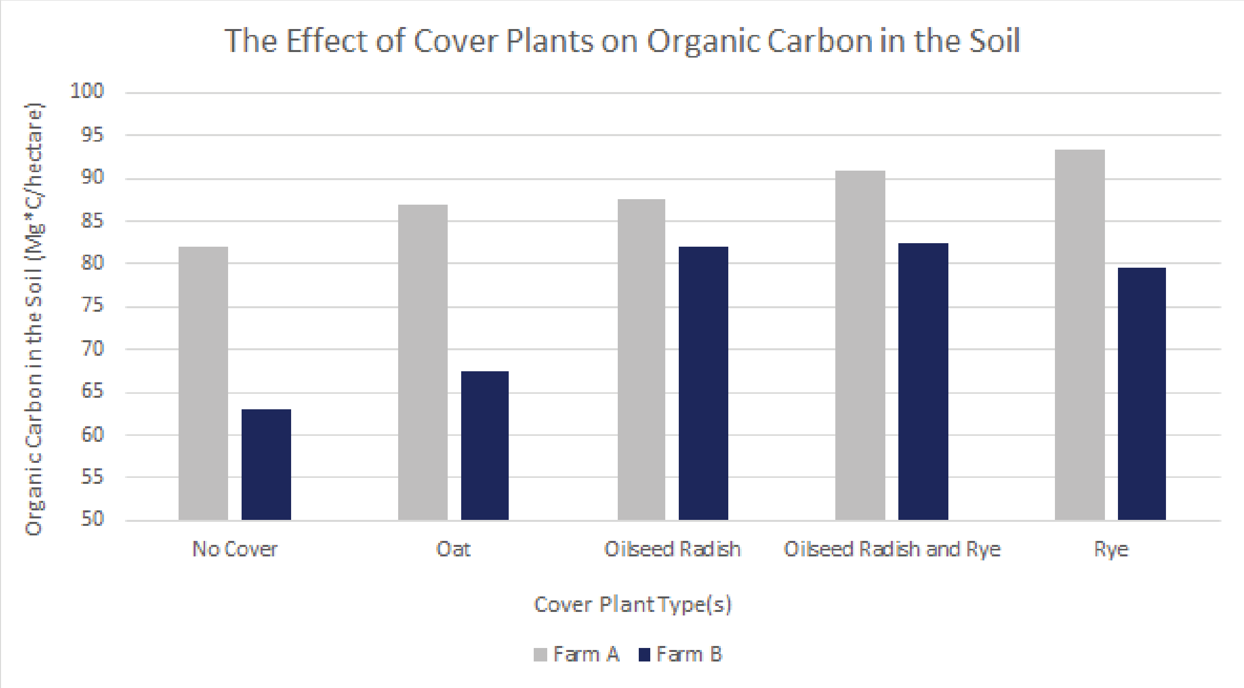
Notes for the Facilitator: With no cover, Farm A had higher soil-carbon levels (82 Mg C/hectare) than Farm B (63 Mg C/hectare). This trend is the same no matter the cover crop conditions, since the organic carbon at Farm A's soil is always higher than the soil in Farm B.

    b. What effect does crop cover seem to have on soil health? Why do you think this is?

Notes for the Facilitator: Cover crops increase soil health because there is more carbon retained in the soil when cover crops are planted. There are many possible answers. Cover crops may help convert carbon dioxide into carbon and put it in the soil. When cover crops decompose, it may add carbon to the soil. Covering the soil prevents gases from escaping from bare soil.

    c. Which cover crop would you plant if you wanted to increase the amount of carbon in the soil? Use evidence from the graph to support your answer.

Notes for the Facilitator: Rye has the greatest effect on soil-carbon for Farm A (increased from 82 Mg C/hectare to 94 Mg C/hectare). Oilseed and Rye together had the greatest effect on soil-carbon for Farm B (increased from 63 Mg C/hectare to 83 MgC/hectare).



Credit: Modified from Chahal, I., Vyn, R.J., Mayers, D. et al. Cumulative impact of cover crops on soil carbon sequestration and profitability in a temperate humid climate. Sci Rep 10, 13381 (2020). https://doi.org/10.1038/s41598-020-70224-6

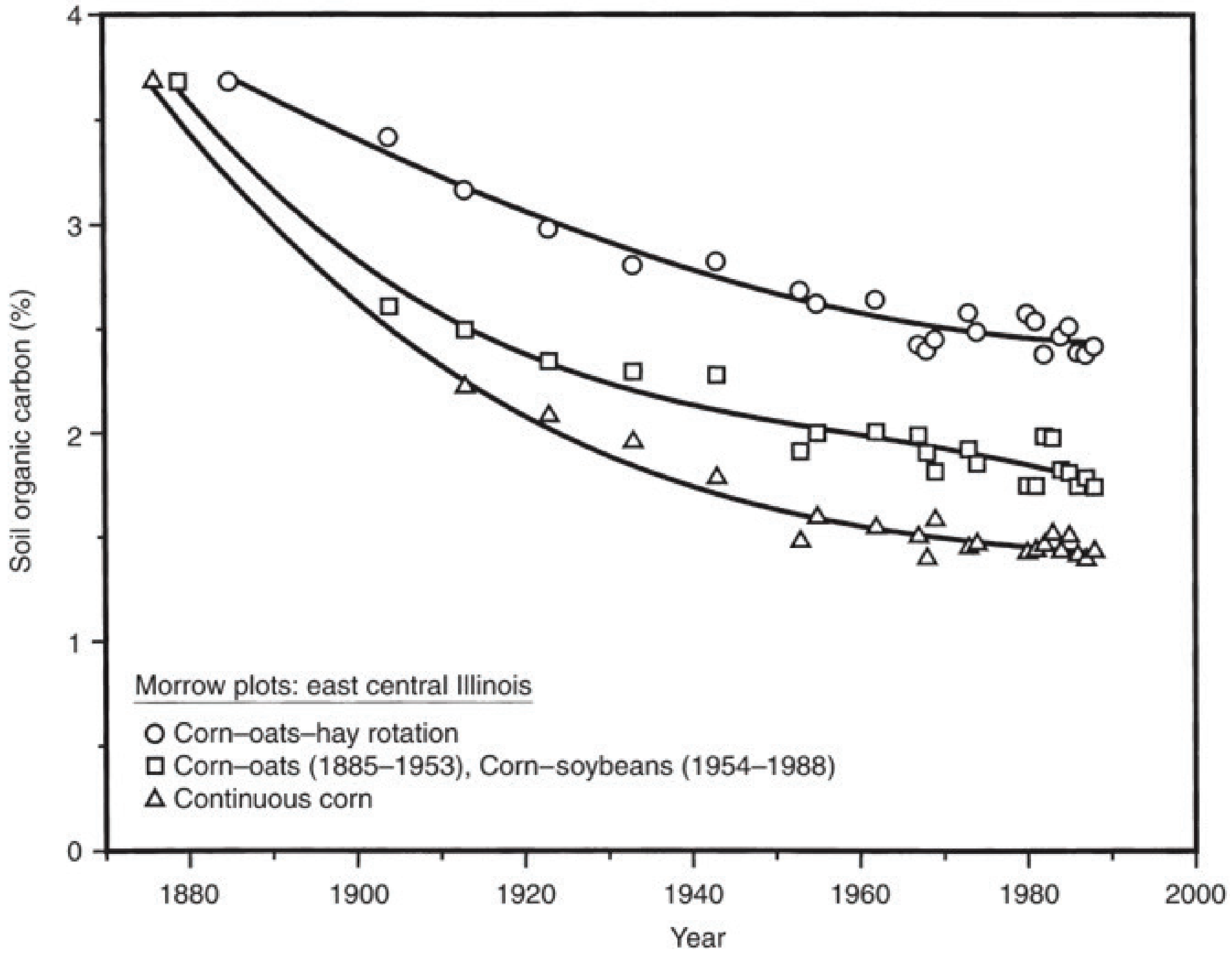
2. Three plots of land were studied to see the effects of crop rotation on the carbon content of the soil. Examine the graph of the "Morrow Plots: East Central Illinois" below.

a. Compare the overall trend of the soil carbon for the three plots.

Notes for the Facilitator: No matter what crops were planted, the soil-carbon content decreased over time. The rate of carbon loss was greatest with continuous corn planting, and was least with rotating corn, oats, and hay. All three lines seem to level off, meaning that carbon loss decreases over time no matter what crop was planted.

b. Which setup would you use on your own farm: continuous corn, rotating corn and oats, or rotating corn, oats, and hay? Why?

Notes for the Facilitator: Rotating corn, oats, and hay caused the least amount of carbon loss from the soil. It had the slowest rate of decline, as well as the lowest overall decline. By the end of this study, this soil would be the healthiest in terms of carbon content.



Credit: Modified from https://www.researchgate.net/publication/267704070_Agricultural_Contributions_to_Greenhouse_Gases_3_Agricultural_Contributions_to_Greenhouse_Gas_Emissions

3. Bacteria and fungi (microorganisms) that live in the soil break down organic matter within the soil. In doing so, these organisms give off gases, such as carbon dioxide, methane, and nitrous oxide, all of which are considered greenhouse gases. The release of gases from the soil to the atmosphere is called flux. Examine the graphs that report the flux between zero tilled and tilled farmland.

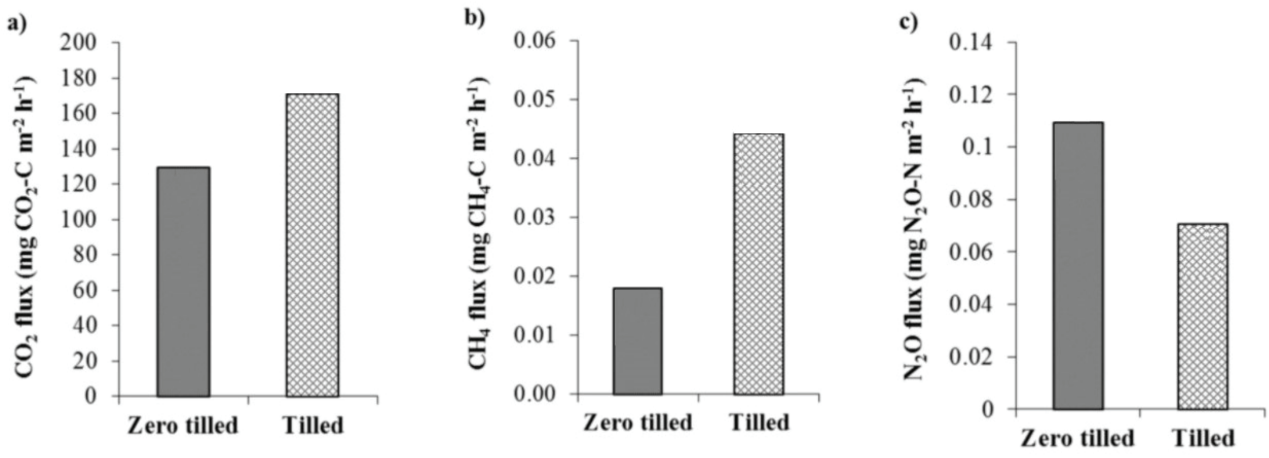
a. Would you expect tilled soils to contain more or less organic carbon than non-tilled soils? Use evidence from the graphs to support your answer.

Notes for the Facilitator: Less, because tilled soils had a greater release of both carbon dioxide and methane. Organisms in the soil convert organics to these gases, but then the tilling causes them to escape the soil faster, meaning there is less of a chance of this carbon being retained in tilled soils.

b. What effect does tilling have on how much of each of these gases are given off by microorganisms in the soil?

Notes for the Facilitator: Tilling disrupts the normal processes of microorganisms, causing more carbon dioxide and methane to be given off. Nitrous oxide has the opposite trend, and less is given off when tilling occurs.

GREENHOUSE GAS RELEASE UNDER TILLING AND NO-TILL CONDITIONS



Credit: https://www.nature.com/articles/srep04586

Consider

1. Which sustainable farming practice do you think will have the greatest impact on reduction of greenhouse gases in the atmosphere (and increase storage of carbon in the soil)? Why do you think this?

Notes for the Facilitator: Answers will vary. The units on the graphs are different, so it's hard to relate them exactly to one another. Look for learners to make an argument based on the data rather than focusing on a right answer.

2. Each greenhouse gas has a similar effect on the environment in that they cause warming but differ in exactly how much warming they can cause.

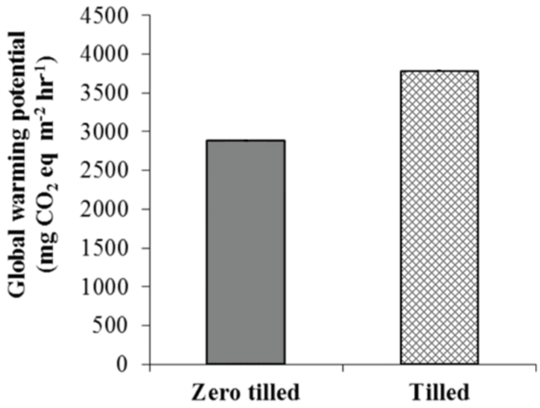
a. Nitrous oxide is capable of warming the environment much faster than either carbon dioxide or methane. Revisit the graphs in step 3 of the procedure and use them to make a recommendation as to whether farmers should till their land or not.

Notes for the Facilitator: From the graphs, one might make the recommendation to till. While tilling increases carbon dioxide and methane, the fact that it causes a decrease in nitrous oxide--the most harmful of the 3 gases--might be an argument for tilling. Others may argue that the amount of carbon dioxide and methane released due to tilling is not worth the drop in nitrous oxide, and so would recommend against tilling.

b. The following graph takes into account how much each greenhouse gas is released due to tilling, as well as how much each gas warms the atmosphere. Using this information, what recommendation would you make to farmers about tilling the land? Explain your thinking.

Notes for the Facilitator: Learners who recommended tilling may change their answer given this information, since tilling is shown to contribute more to warming than non-tilled soils. Learners who recommended against tilling can use this as further evidence to support their argument.

OVERALL GLOBAL WARMING POTENTIAL UNDER TILLING AND NO-TILL CONDITIONS



Credit: https://www.nature.com/articles/srep04586

3. Would you describe sustainable farming practices as a mitigation strategy or an adaptation strategy in terms of climate change? Why do you think that?

Notes for the Facilitator: An argument could be made for sustainable farming practices to be a mitigation strategy. These practices prevent further greenhouse gases from leaving the soil and entering the atmosphere. They also increase soil health, and healthy soil will remove carbon dioxide from the atmosphere, also causing less warming, which could make them an adaptation strategy.

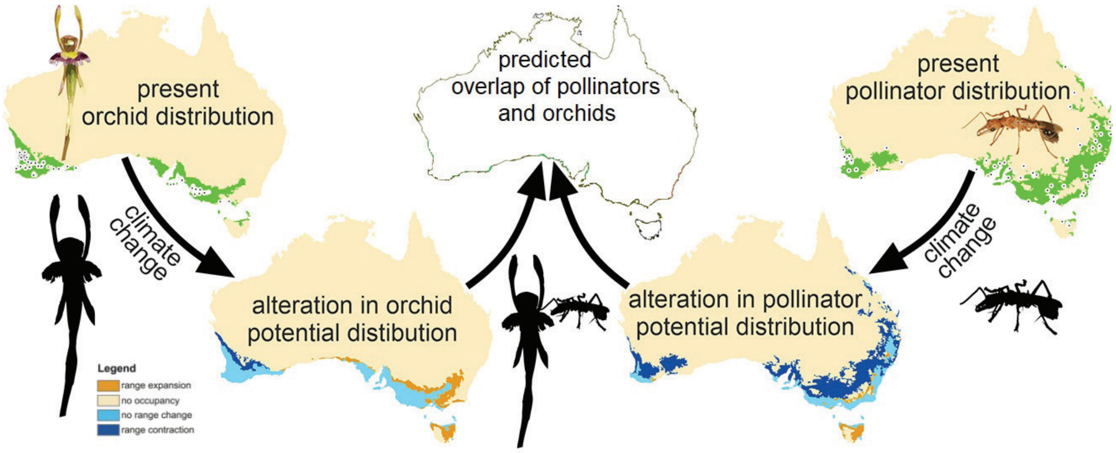
Extension

1. **Applying Concepts:** Many plants, including crops, depend on pollinators, and pollinators depend on plants. The pollinators take food from flowers, while helping the plant to reproduce. However, all living organisms depend on their environment to survive. Due to climate change, many species' habitats will be affected enough to change the range in which they can live. The following diagram shows changes in the distribution of orchid plants and their pollinators along the southern coast of Australia.

   a. Describe the expected changes to each species' distribution given changes in climate.

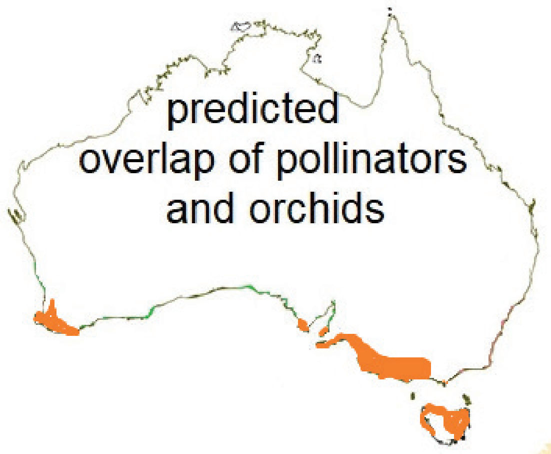
Notes for the Facilitator: The pollinator species will have a much smaller range, as the dark blue represents lost range (range contraction). They will be limited to the southern coast in both the western and eastern regions of Australia. Their range has expanded in Tasmania. The orchid population will have a slightly smaller range on the west coast of Australia, however, has an expanded range on the east coast, as well as in Tasmania.

   b. Indicate on the map labeled "predicted overlap of pollinators and orchids" where the species used to overlap versus where they are expected to in the future.



Credit: **https://www.sciencedirect.com/science/article/pii/S004896972103922X#f0015**

Notes for the Facilitator: The predicted overlap of these two species would is shown in the following map:



Credit: Modified from: **https://www.sciencedirect.com/science/article/pii/S004896972103922X#f0015**

c. Describe how the range in their overlap is expected to change given a change in climate.

Notes for the Facilitator: There is much less overlap of these two species expected as the climate of Australia get warmer, the main reason being the limited distribution of the pollinator. There will be more overlap in Tasmania.

d. How will the change in climate affect the survival of each species?

Notes for the Facilitator: The orchid seems to be less affected by climate change, as it actually had an overall increase in range. The orchid may be relatively well-adapted to warmer climates. The pollinator is predicted to not survive as well in a warmer climate, and so its survival will be decreased versus what it is now. Tasmania, because it is farther south, is likely not as warm as mainland Australia, so the pollinator can survive better there.

e. If we looked at a crop rather than a flower species, how would this affect food production?

Notes for the Facilitator: A majority of crops rely on pollinators to reproduce, so if we looked at a crop pollinated by this insect, we would likely find less food production. There would be a very noticeable decline in food production for crops whose edible portion is the seeds or fruit. For other crops, there would still be a decline in population size.

ESD KIT: IMPACTS OF CLIMATE CHANGE

Sustainable Development Goal 13: Climate Action

ESD KIT PROJECT: DESIGN A RESILIENT CITY

Climate change has been linked to increased greenhouse gas emissions (especially carbon dioxide) due to the rate at which fossil fuels have been used over the past 150 years. The increase in average global temperature leads to further changes, such as sea level rise and changes in weather patterns. Each of these effects can impact both ecosystems and cities. In this project, you will design a city that is resilient to the effects of climate change. Resiliency here is defined as implementing adaptation or mitigation strategies. Mitigation strategies will help reduce your city's impact on fossil fuel emissions, and therefore future climate change. Adaptation strategies will help alleviate the current effects caused by climate change.

Getting Started

Start by looking at your city or a city nearby where you live.

1. What is your community's climate? What are features of the environment or weather patterns that you have seen in your area that would support your answer?

2. Consider your city, or a city nearby you that has similar environment, weather and climate patterns to where you live. Are there any trends in architecture that are common in this city that you think might be related to its climate?

3. How close is this city to a major body of water? What are some benefits of being near water?

4. What are some effects of climate change that directly impact this city?

5. Look at a map of the city to study its layout.

   a. Where in the city do most people live?

   b. Where are the businesses located?

   c. What does the city manufacture? What does it need to import?

   d. Where are green spaces located in the city?

6. Think about climate-related adaptation and mitigation strategies.

   a. What adaptation or mitigation strategies does this city already have in place related to climate change?

   b. Can you think of any adaptation or mitigation strategies that are not being used in this city but that may be appropriate? What would you suggest and why?

Revisit Investigation 1: Considering Climate. You analyzed how the climate of an area relates to the weather patterns. Start with this information when it comes to deciding where you would like the city you design to be located. Consider the challenges that would come with building in certain climates.

Design a City

How might you design a city that is more resilient to the effects of climate change than the one you examined? Consider the location you chose for the city, and ask yourself:

1. What specific mitigation and adaptation strategies would reduce the effects of climate change?

2. What strategies would make sure the city reduces its impact on future climate change?

Revisit each of the Investigations in this ESD Kit. How can what you learned guide you in designing your city?

Notes for the Facilitator: The following questions can also be found in the Learner Guide. Possible solutions and references are provided to help you assist learners should they need suggestions, hints, or resources as they are considering their city design. Learners are encouraged to incorporate as many ideas into their design as they can.

Investigation 2: Greenhouse Gases and Climate

- How does the city you are designing exchange carbon dioxide with the atmosphere?

  - What in your city gives off carbon dioxide?

Notes for the Facilitator: This will vary depending on the major industries learners include in their city. All cities will have transport and electricity needs. Others may include airports, nearby farms, or manufacturing plants. Some construction materials, such as concrete, also emit carbon dioxide. The Carbon Monitor website can be used by learners to see the average emissions used by different sectors in different countries: **https://carbonmonitor.org/** so they know which sectors are most likely contributors for their region. The EPA also has an excellent source of information on sources of carbon emissions: **https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions**.

  - How could the amount of carbon dioxide given off by a city be monitored?

Notes for the Facilitator: While individual cities do not currently monitor greenhouse gas emissions, studies are being conducted on how this can be done. This question may require research into carbon emissions monitoring, or provide the following resources as an introduction on how these emissions are tracked:

Glasgow is one of the first cities to attempt to monitor greenhouse gas emissions: https://theconversation.com/how-measuring-emissions-in-real-time-can-help-cities-achieve-net-zero-172651

Satellites can be used to monitor emissions: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Carbon_dioxide_monitoring_satellite_given_the_shakes

The Global Monitoring Laboratory provides a comprehensive source for information on greenhouse gas monitoring: https://gml.noaa.gov/ccgg/carbontracker/

Investigation 3A: Measuring Carbon Dioxide and Acidity

- How does the city you are designing contribute to the production of acid rain? What strategies could reduce the city's contribution to the production of acid rain?

Notes for the Facilitator: The Environmental Protection Agency Acid Rain Student Site resource can be provided for students who need help with this question: **https://www3.epa.gov/acidrain/education/site_students/whatcauses.html#:~:text=Power%20plants%20release%20the%20majority,These%20pollutants%20cause%20acid%20rain**

- Does the city you are designing receive acid rain? If so, what modifications can be made to mitigate the effects of acid rain?

Notes for the Facilitator: Answers will vary based on your location. Revisiting the map in the Extension section of Investigation 3A can help determine the answer. The best adaptations to handle acid rain include the maintenance of healthy soils, which can buffer the effects of acids on the environment. Reduction of greenhouse gas emissions would be an appropriate mitigation strategy.

Investigation 3B: Reduction of Greenhouse Gas Emissions

- How can individuals or businesses reduce their carbon emissions?

Notes for the Facilitator: Switching to the use of renewable energies would decrease the use of fossil fuels. Specific recommendations could include: installing rooftop solar panels on homes, using building materials that help maintain building temperature so less energy is used for heating and cooling, or using locally sourced materials to reduce fossil fuels used for transport.

- What can you add to or build within the city you are designing that would reduce carbon dioxide levels in the atmosphere?

Notes for the Facilitator: Adding greenspace, especially trees, can reduce carbon dioxide level, since plants use carbon dioxide for photosynthesis. Trees store more carbon than most other plants, due to the nature of wood. There are also new technologies that can capture carbon dioxide, such as porous asphalt. More information on this asphalt can be found here: **https://reliablepaving.com/blog/asphalt-and-carbon-sequestration/**

- What are the other greenhouse gases? How could the city you are designing emit them. How could these emissions be reduced?

Notes for the Facilitator: Resources can be used to estimate greenhouse gas emissions. For example, this map can help quantify approximately how much methane is released within a certain region: **https://spacenews.com/ghgsat-unveils-free-global-methane-map/.** Reduction of methane mainly concerns changes in waste management and agricultural practices. This map similarly shows nitrous oxide emissions: **https://qz.com/1745204/maps-of-nitrous-oxide-emissions-a-potent-greenhouse-gas/**.

Investigation 4A: Testing Heat Capacity

- If the city you are designing is located near a large body of water, how is the city's climate affected by that water?

Notes for the Facilitator: For learners that need help answering this question, provide this resource: **https://oceanexplorer.noaa.gov/facts/climate.html**

- If the city you are designing is not near a body of water, how will this affect trade and transport? How will this in turn affect the amount of carbon emissions?

Notes for the Facilitator: Cities not near waterways need to use more trucks, trains, and planes to transport people and goods. The graph on this site shows the relative contribution of boats, planes, and road transport on emissions: **https://www.europarl.europa.eu/news/en/headlines/society/20191129STO67756/emissions-from-planes-and-ships-facts-and-figures-infographic**

Investigation 4B: Coastal Storms

- How could the city you are designing be affected by coastal storms?

Notes for the Facilitator: Answers will vary based on proximity to the coast. If the city being designed is coastal, then erosion, flooding, and damage to buildings are the most likely concerns.

- What structures could be built to mitigate the effects of coastal storms?

Notes for the Facilitator: There are many possible adaptation strategies, including elevation or relocation of homes, levees, salt marshes, offshore mangrove forests, and reefs. A combination of these strategies is likely to be the most effective way to reduce coastal storm impacts.

Investigation 5A: Ice Melting, Thermal Expansion, and Sea Level Rise

- How could the city you are designing be affected by the current sea level?

Notes for the Facilitator: Answers will vary based on proximity to the coast. Accessing local maps will allow learners to measure how far from specific bodies of water they want their city to be. The Intergovernmental Panel on Climate Change provides information on the effects of sea level rise on coastal cities or cities near sea-level: **https://www.ipcc.ch/srocc/chapter/chapter-4-sea-level-rise-and-implications-for-low-lying-islands-coasts-and-communities/**.

- Given future predicted sea levels, how could the city you are designing be affected by sea level rise?

Notes for the Facilitator: Answers will vary based on proximity to the coast. Answers will also vary based on which predicted model the learners use (low, moderate, or extreme impact) as introduced in Investigation 5B.

Investigation 5B:

- What structures could be built to mitigate the effects of coastal flooding?

Notes for the Facilitator: Many of the strategies to handle coastal storms will also apply here.

Investigation 6A: Albedo

- Considering the climate your city will be in, how can buildings be constructed to minimize heat or air conditioning use? What building materials could be used?

Notes for the Facilitator: Consideration of building sizes and materials will have the most effect on the interior temperature of the buildings. This resource has many ideas in case learners need assistance in answering this question: https://www.energy.gov/energysaver/energy-efficient-home-design. The most common materials used worldwide are described here: **https://proest.com/construction/tips/common-materials/**

- Consider the albedo of the building materials. How do they contribute to the Urban Heat Island Profile of the city?

Notes for the Facilitator: Most construction materials have low albedos (under .2), meaning they absorb most solar radiation that hits them. Source: **https://www.sciencedirect.com/topics/engineering/albedo**

Investigation 6B: Albedo Enhancement

- How could you design a city to have a high albedo? What alternative materials might be used to construct the buildings in your city?

Notes for the Facilitator: This resource can help learners determine what alternate building materials might be appropriate in the city they design: **https://inhabitat.com/11-green-building-materials-that-are-way-better-than-concrete/.** Another excellent resource for altering the city can be found here: **https://www.energy.gov/energysaver/cool-roofs**

Investigation 7A: Effects of Climate Change on Terrestrial Ecosystems

- How close will farms be to the city you are designing? Consider the impacts of trade and transport, and the impacts on the soil close to the city.

Notes for the Facilitator: Answers will vary based on location. The farther the city is from farms, the more transport will be required to get food to the city, which will result in an increase in fossil fuel emissions.

Investigation 7B: Sustainable Farming Practices

- Consider how cities impact soil quality. How could you design your city to reduce its impact on the soil?

Notes for the Facilitator: Surface runoff from cities is a major concern. While this does not contribute directly to climate change, the pollutants found in urban runoff can decrease soil quality, which in turn affects how much drawdown can occur in these soils. The use of pervious pavements can help reduce runoff to bodies of water or other areas outside the city. If farms are included within your city limits, implementing sustainable farming practices is another option for increasing soil quality.

Make a Map of Your City Design

1. "Downtown" with businesses
2. Housing
3. At least five specific Adaptations or Mitigation Strategies to address possible effects of climate change

Other Considerations

Additional Impacts due to Climate Change

The Investigations you completed within this ESD Kit covered many impacts of climate change; however, there are others that you might consider depending on the location of the city you design. Your city may be affected by an increase in the number and severity of droughts, wildfires, severe inland storms and flooding. A good resource that summarizes these effects can be found here: **https://ec.europa.eu/clima/climate-change/consequences-climate-change_en**. Many cities have adaptation strategies for these effects that you may want to include in your design.

Power Supply (source, transmission lines)

Buildings within cities are reliant on a source of energy. The energy required for most human-made products is most often electricity. A majority of electricity is generated by the burning of fossil fuels, although there are many alternative sources (e.g., wind and solar) that do not use fossil fuels and so do not release carbon dioxide and other greenhouse gases. When designing your town, consider what fuel sources could be readily available given where in the world the city is located. Will the power supply be locally generated, or does it need to be transmitted into the city? How will the main source of energy contribute to carbon dioxide emissions, or will the city focus on the use of clean, renewable energy sources?

Transportation Needs

Most modes of transportation use fossil fuels as an energy source and so contribute to greenhouse gas emissions, especially carbon dioxide. Emissions can be decreased when fewer individuals use cars and public transportation is readily available. The size and walkability of the city also contributes to how often cars and other transportation is required. Taking these factors into consideration when designing your city can result in lower emissions.

Sensing and Control

Being able to automatically sense changes and control responses to them can save energy and can reduce the amount of greenhouse gases released by burning fossil fuels. For example, heating and cooling buildings uses a great deal of energy. Having a system that automatically senses temperature and turns on air conditioning and heat only when necessary can save a lot of energy.

Sensing can also be used to monitor greenhouse gas emissions, atmospheric temperature, water acidity, and other factors related to climate change. Monitoring these factors can help a city focus on early warning indicators and react to changes before they become unmanageable. Consider what you may want to monitor in your city, and how, to implement adaptation strategies before large changes occur.

Present Your Solutions

You can describe and show your city plan in various ways:

- written report
- a slide show
- an animated *Scratch*® presentation
- an oral presentation with visuals or a model, which may also be video recorded

ESD KIT:
IMPACTS OF CLIMATE CHANGE

Sustainable Development Goal 13: Climate Action

APPENDIX 1: USING *SCRATCH*® WITH THE ESD KIT INVESTIGATIONS: TIPS AND TECHNIQUES

An important aspect of your work with ESD KitS is reporting and presenting the results of the Investigations and ESD Kit Project. This can be done in a variety of ways: written reports, slide shows, videos, and oral presentations. *Scratch*® is a highly recommended platform to report and present findings or designs for projects. *Scratch*® is a programmable learning environment that enables you to design and build your own interactive stories, games, and animations — and to share your creations with others in the online community. *Scratch*® is also a good vehicle for creative and interesting ways to visualize data. In the process, you will also learn how to code.

If you are not already familiar with the basics of *Scratch*®, first look at *Getting Started with Scratch*®, which tells you how to set up an account on the *Scratch*® website and where to find introductory tutorials and guides. If you are familiar with *Scratch*®, skip ahead to *Tips and Techniques for Scratch*® for how to work with *Scratch*® to share what you learn while working through the ESD Kit Investigations.

Notes for the Facilitator: You should be familiar with the basics of *Scratch*® so as to be able to assist learners with their activities and projects. You can achieve this by following *Getting Started with Scratch*®, working on the same tutorials that learners will use.

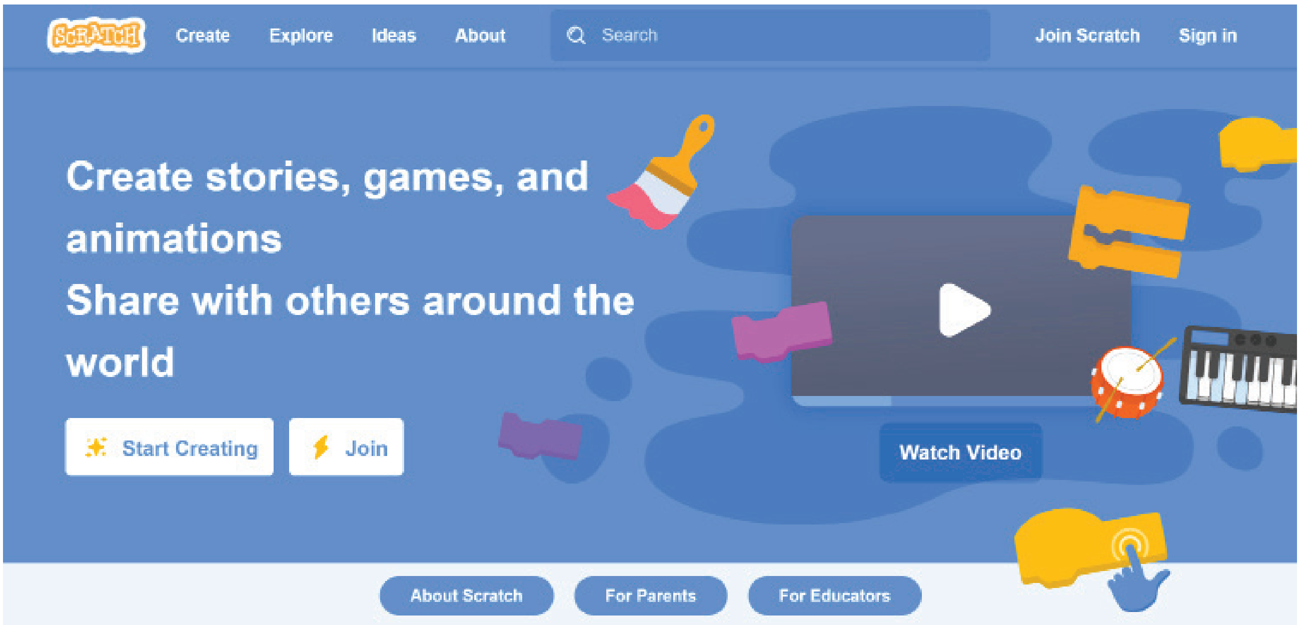
Scratch® Tips and Techniques goes into detail about topics that are directly relevant to ESD Kit activities, especially how to incorporate data into *Scratch*® projects and create interesting and novel visualizations of that data. There are links to sample *Scratch*® projects that both facilitators and learners can look at, learn from, and remix.

Some of the Investigations include suggestions for optional *Scratch*® activities. In your preparation to facilitate Investigations, review the *Scratch*® activity and look at any sample *Scratch*® projects that are linked to it.

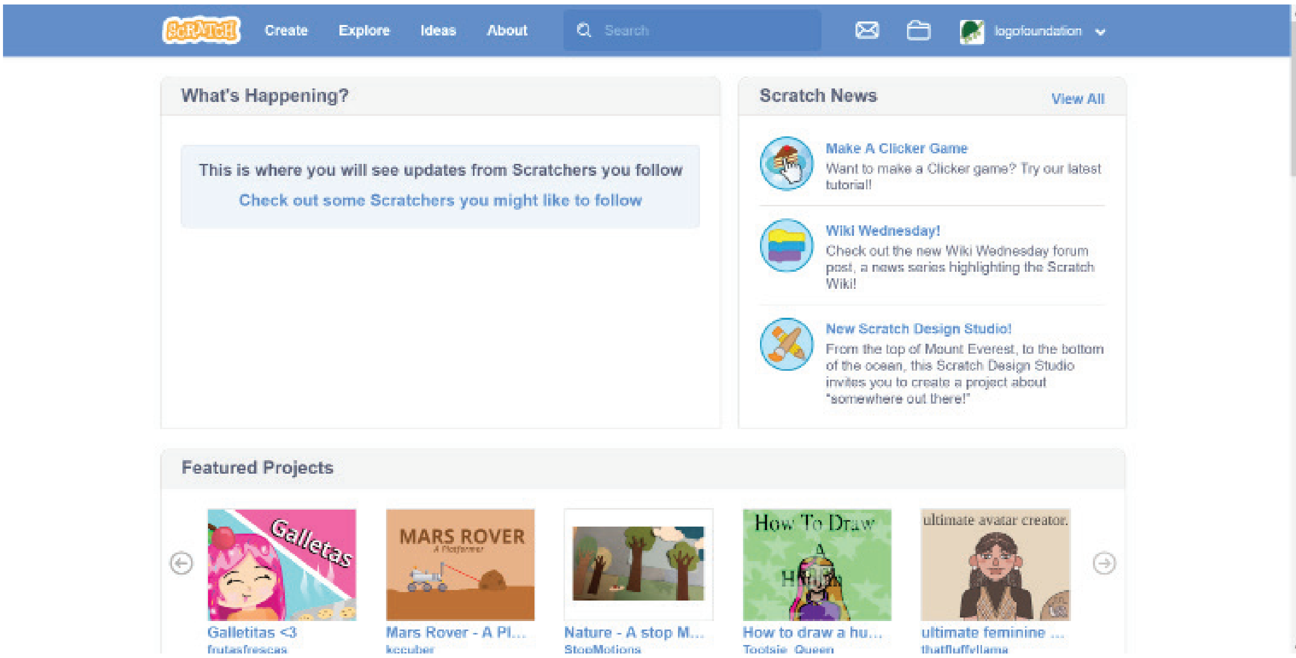
Getting Started with *Scratch®*

Scratch® works in your Web browser. There is no need to download and install an application. Your projects are saved automatically in the cloud. You can sign into your account from any computer and have access to everything you have created.

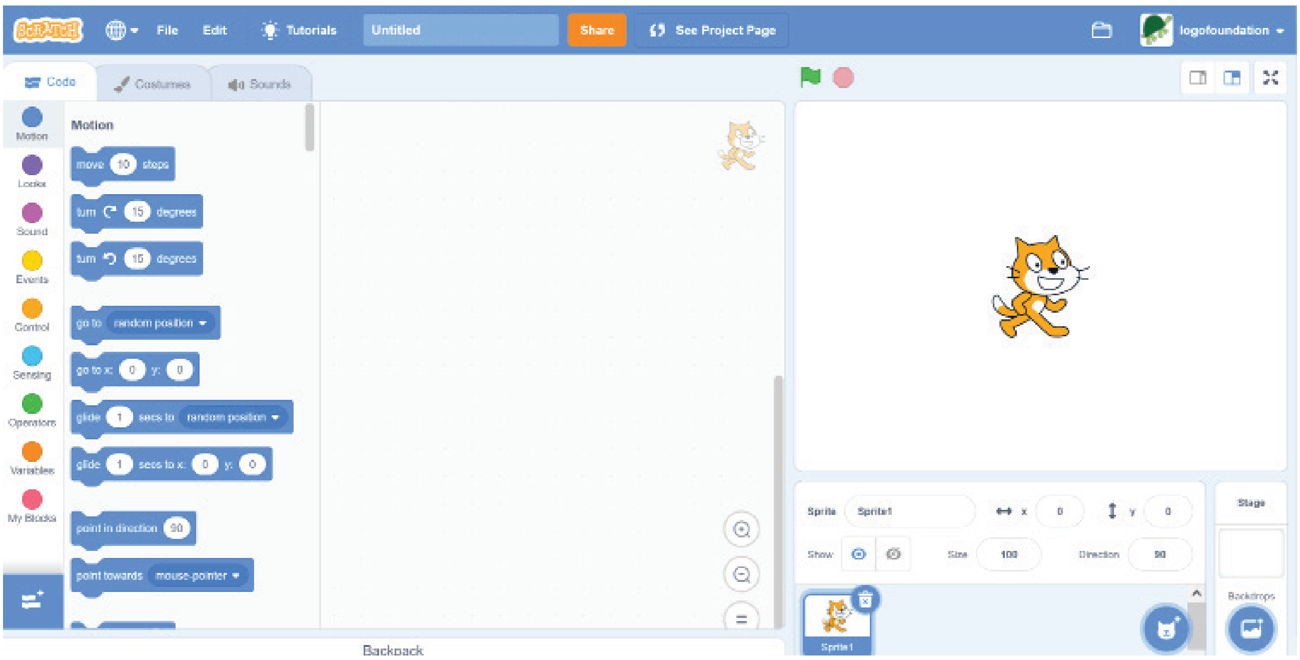
To get started, go to the *Scratch®* website: https://scratch.mit.edu/ This is what you'll see:



You should first create your own account on *Scratch*® so that you can save your work and share and communicate with other Scratchers. Click the **Join** button at the lower left or **Join Scratch** at the upper right. Follow the steps to set up your account. Once you are signed in, the *Scratch*® homepage will look something like this:

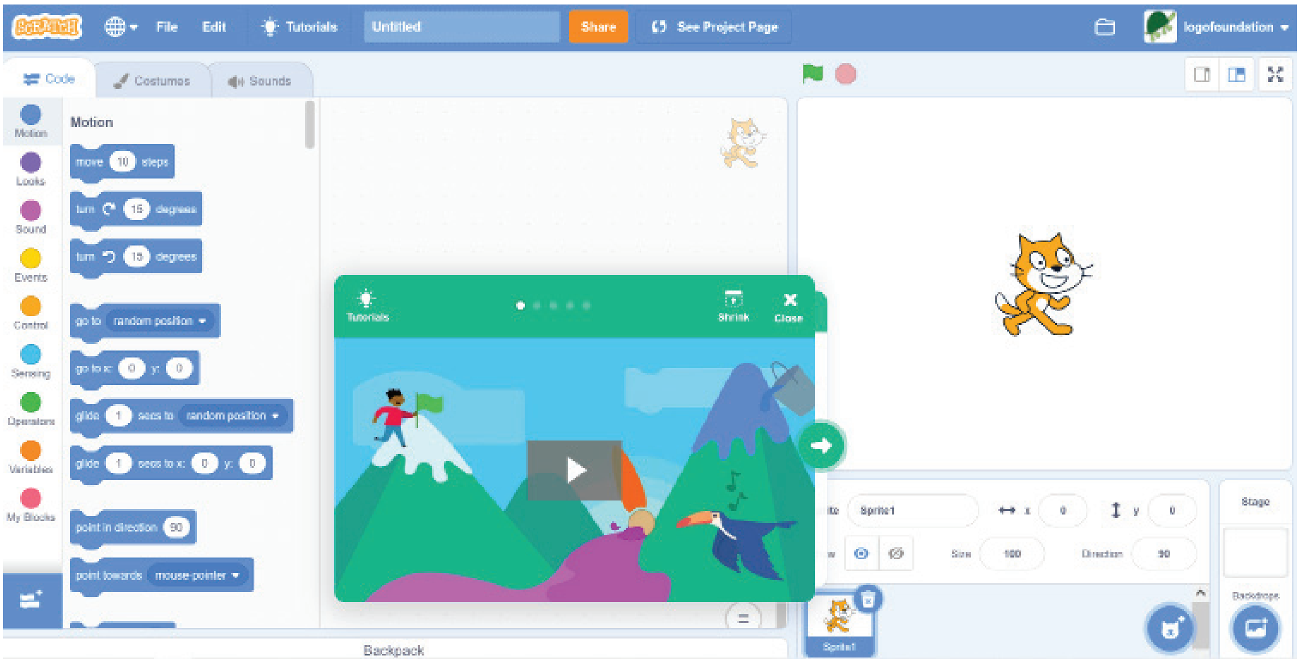


Your username appears at the upper right. You can browse the **Featured Projects** and other projects that appear as you scroll down the page. To get started yourself, click on **Create** at the upper left. This will take you to the *Scratch*® Editor. Your screen will look like this:



You can watch a brief video that shows some of the many things you can do with *Scratch*®. You can also jump right in by clicking on **Create** at the upper left or **Start Creating** at the lower left. This will bring you into the *Scratch*® Editor with an introductory tutorial running.

Click on **Tutorials** at the top of the page to go to a page with links to more than two dozen tutorials that will get you started with *Scratch*®. Each one appears in a window over the Editor.



You can stop and start, and back up as you need to. As you follow the tutorial, you will create your version of the project in the *Scratch*® Editor. Initially it will be called Untitled. You can click on the name and change it. It will automatically be saved in your *Scratch*® account.

More Resources

In addition to the resources on the *Scratch*® website, the *Scratch*® Wiki https://en.scratch-wiki.info/ has a great deal of information about *Scratch*®.

The *Scratch*®ED website at https://scratched.gse.harvard.edu is an archive of documents and projects created by *Scratch*® Educators.

For very young children there is *Scratch*® *Jr*, which you will find at http://www.scratchjr.org/. You may download and install it on your iPad or Android tablet. There is also a version for Chromebooks.

Scratch® Tips and Techniques

Putting on a Show

You can think of your *Scratch*® program as a theater. Your screen is the stage, and the backdrops are the scenery. The actors in your show are called sprites. They can wear a variety of costumes, move around, talk, sing, and interact with each other. Your show can have several scenes. To change from one scene to another, you can write the program to change the backdrop, hide characters that won't appear in the next scene, and get new characters to appear.

Working with Images

There are dozens of backdrops for the stage and costumes for the sprites that are built into *Scratch*®. You can choose which ones you want to use. You can also import images into *Scratch*®. These can be your own photos or images produced using other applications or downloaded from the internet. There is also a Paint Editor that you can use to draw backdrops and costumes or to alter existing images.

Visit this page for more information about using images in *Scratch*®: **https://digitalmaestro.org/articles/prepare-images-for-use-in-scratch-code-projects**

Displaying Text

One way to include text in your project is to use the paint program to create or modify a backdrop for the stage, or a costume for a sprite. Click on the letter T and then click where you want to begin your text. This creates a text box where you can type your text. You can also paste text that you have copied from another application. Once you have written some text, you can select the text box with the pointer icon to resize, move, or rotate it. If your text is on a sprite costume, you can make it move around by programming the sprite to move. Text on backgrounds or costumes will remain on the screen until the scene or costume changes.

Another way to use text is to use the **say** or **think** blocks. These can be found in the "Looks" tab to the left of the *Scratch*® program. These will display comic book style balloons with text in them next to your sprite. You can also choose how long these balloons appear, and you can program as many as you want to use in a scene.

Sounds

Using the Text to Speech extension, a sprite can say what you type into the **speak** block.

Scratch® can also play recorded sounds. These can be music, sound effects, and spoken words. You can record music or your own voice in *Scratch*® and then play it as part of your project. To do this, click on the Sounds tab, then on Choose a Sound, then on the microphone icon.

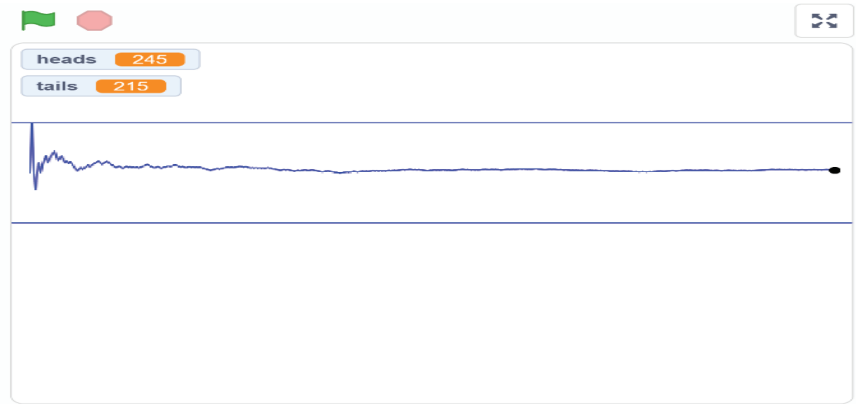
In addition to recorded music, there is a music extension that you can use to create melodies note by note, to be played by a variety of online instruments.

Working with Data

When trying to understand the significance of some data, it is helpful to have a visual representation rather than just a list of numbers. We often see line and bar graphs, pie charts, and other diagrams used for this purpose. For example, look at *Investigation 4: Understanding Our National Energy Mix* and *Investigation 7B: Logging Temperature Automatically Using a micro:bit* where data is used to create graphs. *Scratch*® can be used to draw graphs, but it also adds the ability to create a wider range of visual representations of data that can also be dynamic and interactive.

For example, look at the *Scratch*® project Coin Toss: **https://scratch.mit.edu/projects/486312136/**

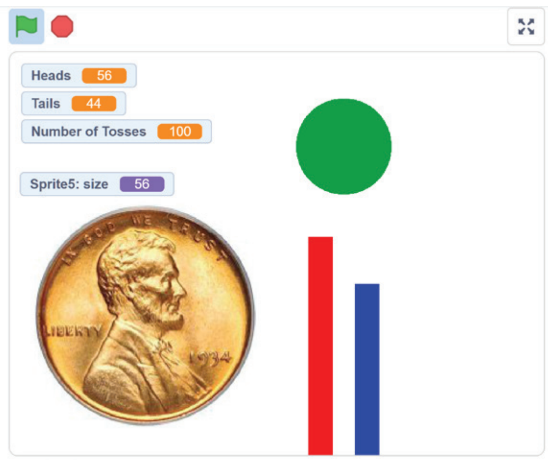
It uses the **pick random** block to simulate tossing a coin 460 times. It creates a graph showing the percentage of heads as the tossing progresses. The graph looks different each time the program is run, but the following image is typical. In *Scratch*®, you can watch this emerge as the graph is drawn in real time.



Another coin tossing project is Coin Toss Visualization: https://scratch.mit.edu/projects/2207857/

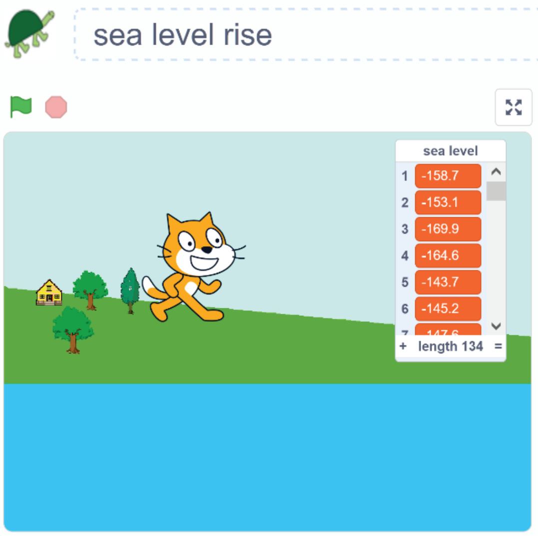
The coin is flipped 100 times and the visual representations of the proportions of heads and tails emerge dynamically. In addition to a bar chart, the size of the green circle increases and decreases based on the percentage of heads up to that point.

In addition to visualization, there is sonification. The pitch of a note played on a virtual piano reflects the percentage of heads.

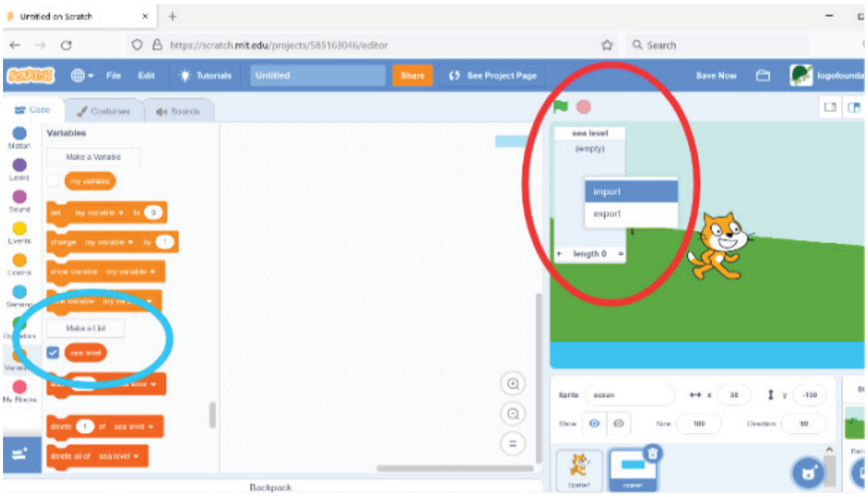


In the coin tossing projects, the program generates the data for the visualizations. You can also bring outside data into a *Scratch*® project.

The sea level rise project at **https://scratch.mit.edu/projects/585163046/** uses global mean sea level data for the years 1880 to 2014 from the **Climate.gov** website. To bring this data into *Scratch*®, we first download it from **Climate.gov** as a .csv file (Microsoft Excel). We then create a list named "sea level" and imported the data into it. Here is how to do that:



Go to the variable section of the code tab and click on Make a List. Give the list a name. The list appears on the stage. (You can make it invisible by unchecking the blue box next to the name.) Now right-click on the list and you will see the option to import or export data. Click input and then select the .csv file you want to import. You can only import one column of a .csv file into the list. If there are more columns in the file, *Scratch*® will ask you which one you want to import. The sea level data file from Climate.gov has three columns. The second column has the data we need on sea level.



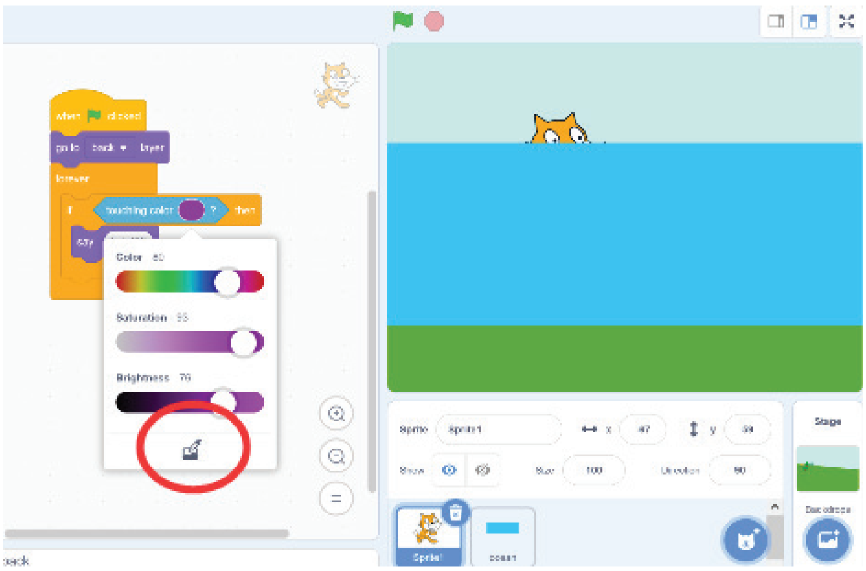
Once the data is imported, you may have to do some touching up. Often a .csv file will have a label in the first row of each column. This label will be imported into the *Scratch*® list along with the data below it. To remove this label and leave only data in the list, click on that first item. An X will appear in it. Click the X to remove the item.

Now the list of sea level data is ready to use. Create a variable named "pointer." This is used to step through the list of data one item at a time. The Y coordinate of the ocean sprite is set to each value of the sea level data in turn until the end of the list is reached.

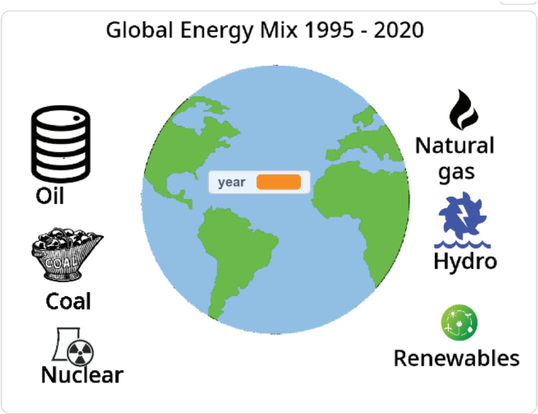
To see more about how the program works, go to the code tab of the ocean sprite, and look at the comments attached to the code for an explanation.

The cat is also programmed to cry out for help as the sea level rises and touches her. The code looks to see if the cat is touching the color blue (the sea) and causes the cat to say "Help!!!" when that happens. Look at the code tab of the cat sprite to see that program.

To get the correct color into the **touching color** block, click on the color oval in the block and then on the color picker icon below the sliders. Then click on the color that you want to pick up. In this case, that's the blue of the ocean sprite.

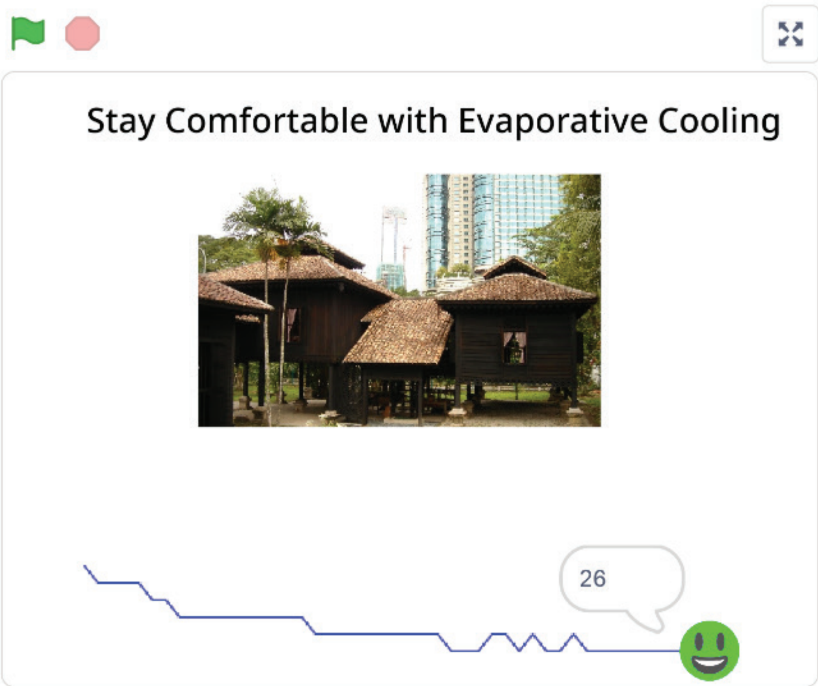


Investigation 4: Understanding Our National Energy Mix looks at the distribution of different energy sources over time. The data are represented by line graphs. The *Scratch*® project *Global Energy Mix* https://scratch.mit.edu/projects/573662932/ visualized that same data by increasing and decreasing the sizes of icons representing each energy source. You can remix it to use your own icons. You could extend the time frame so as to include projections of the energy mix in the future.



In *Investigation 7B*: ***Logging Temperature Automatically Using a micro:bit***, temperature data will be logged using a micro:bit. The data, when downloaded from the micro:bit as a .csv file can be used to make a graph or *Scratch*® program. Using Excel, we can create a line graph in the .csv file, showing the change in temperature under a damp clay flowerpot over a period of 47 minutes.

The *Scratch*® project *Evaporative Cooling* (https://scratch.mit.edu/projects/574196032/) uses that data to draw a line graph in a somewhat different way.

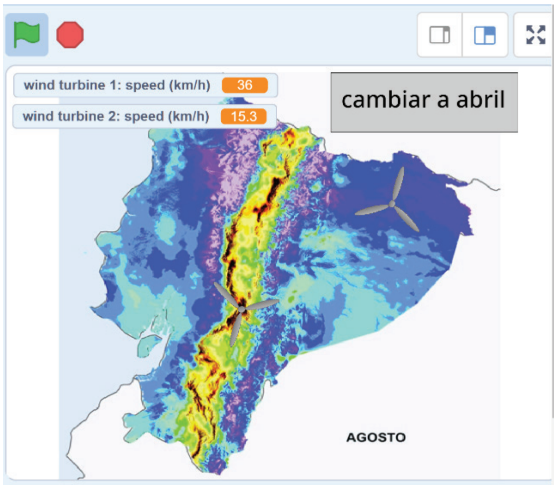


Making Your *Scratch*® Project Interactive

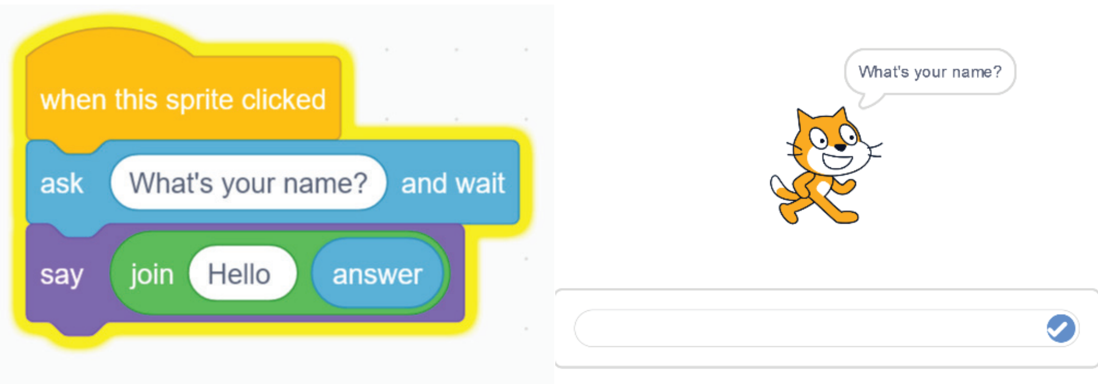
Anyone who uses an interactive *Scratch*® program can affect the course of action, what appears, and the sounds, voices, and music that are heard. Here are some examples:

Exploration 3B1: Locating Wind Energy shows how the potential for wind power in Ecuador varies from one location to another. In the *Scratch*® project Ecuador Wind Power (**https://scratch.mit.edu/projects/579828042**), the colors on the map indicate average monthly wind speeds. There are two sprites in the shape of wind turbines that can be dragged around the map. They are programmed to detect the color they are touching and set the wind speed accordingly. These values appear at the top of the screen. To actively visualize the data, the wind speed variables determine how rapidly each wind turbine spins.

Sprites can be programmed to detect color or other sprites. They can respond to a mouse click. They can be dragged with the mouse or by using specific keyboard keys. Other keypresses could be programmed to trigger other actions.



The **ask** and **answer** blocks allow you to prompt the user for a response and take action based on what they type into the dialog box that appears.



Here, the cat asks, "What's your name?" When you type in your name and click the check box, the cat replies with "Hello" followed by your name.

You can use this feature to determine the flow of your program. For example, you could create a project where you ask whether the user wants to learn more about Coal or Gas. The response could trigger a switch to an appropriate backdrop and start a flow of information and actions on the chosen topic.

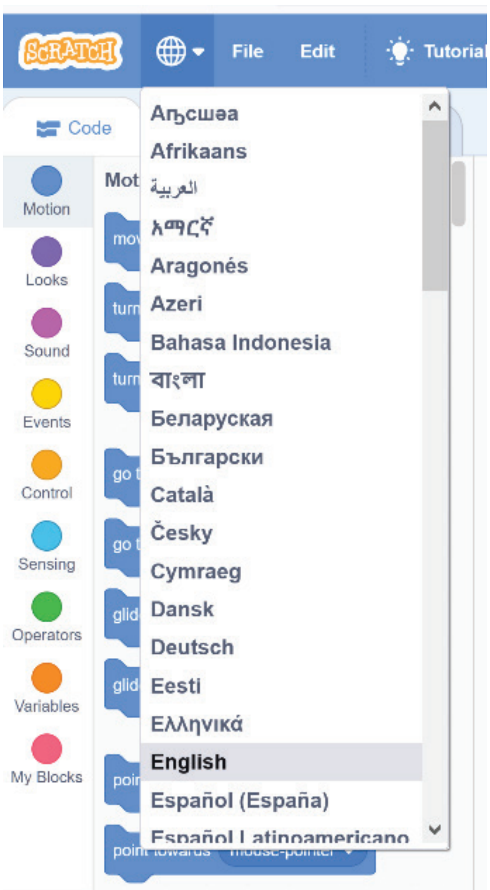
Look at the Sensing section of the Blocks Palette for some additional ways to make your *Scratch*® project interactive.

Changing Language

Scratch® supports many languages. Click on the globe icon in the upper left corner and you will see a list of the available languages. When you select one, the text on the code blocks, the menu items, and other text elements of the *Scratch*® user interface change to that language.

This makes it possible for Scratchers worldwide to work in their own language. It is also useful when looking at a project that someone has created with *Scratch*® set to a language other than your own. You can switch to your language and the code blocks will change so that you can better understand the project.

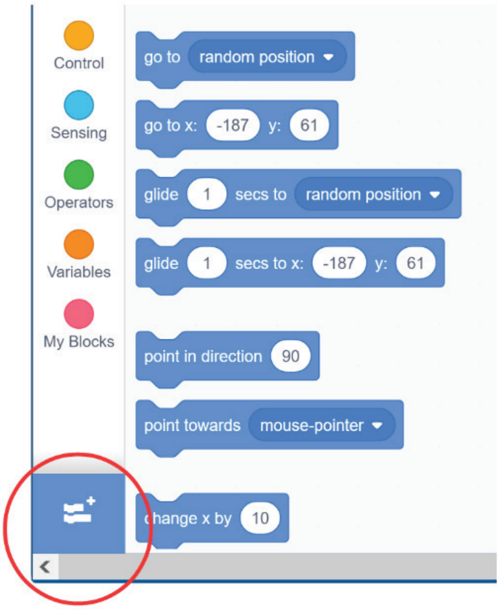
This feature does not change the text that the user has written on backdrops or sprite costumes, or text written into the **ask**, **say**, or **think** blocks. There is a separate translation extension to change these features.



Scratch® Extensions

A *Scratch*® Extension is a collection of code blocks for a specific purpose. The Pen extension enables Sprites to draw lines as they move. This is used to draw line graphs in the Evaporative Cooling and Coin Toss projects shown above. The Coin Toss Visualization project uses the Pen extension along with the music extension.

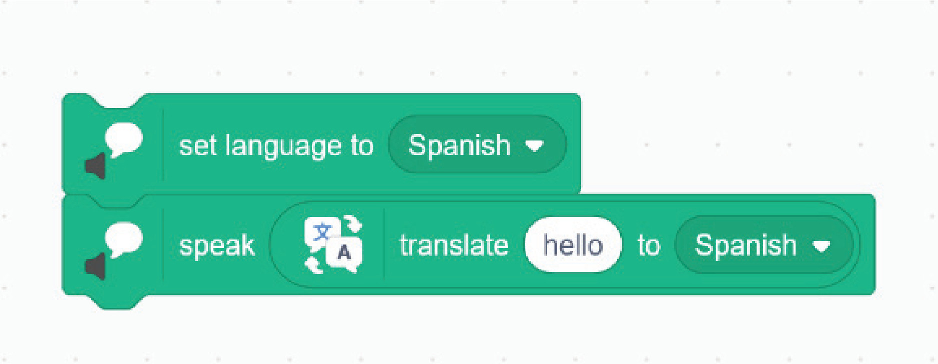
To use an extension, click the icon at the lower left of the *Scratch*® Screen. This brings you to a page where you can select the extension you want to load.



There is an extension for micro:bit which allows *Scratch*® to respond to various movements of the micro:bit as well as the pressing of the buttons on the board.

With Video Sensing, *Scratch*® responds to movements picked up by the computer's camera.

Text to Speech produces audible speech of the written words you type into the speak block. Translate take the text you type into the translate block and reports it translated into the language you specify. It's interesting to use these two extensions together. With the code at the right, you will hear *Scratch*® say "Hola."



Sharing and Remixing *Scratch*® Projects

There are millions of projects shared on the *Scratch*® website. Examining these projects is an effective way to learn more about *Scratch*® programming and project building, as well as about the content conveyed in the projects.

When you first create a *Scratch*® project, it is private so that only you can see it. You can share it so that everyone else who visits the *Scratch*® website can also view it. In either case, only you can make changes to it. But *Scratch*® also allows you to remix someone else's project, making a copy of it for yourself. Here is how that works:

Sign into your *Scratch*® account and go to a project you are interested in. You will see a green "Remix" button at the top of the Projects Page. When you click this, a copy of the project will be saved in your account. It will have the same name as the original project with the word "remix" added at the end. There will be a message at the top of the Projects Page crediting the author of the original.

You are now free to alter it, add to it, use parts of it in another project of yours. You can share your resulting project. For more information about remixing, look at: **https://en.scratch-wiki.info/wiki/Remix**

Additional *Scratch*® Projects Related to the ESD Kits

Here are some examples of Projects created by *Scratch*® users and shared on the *Scratch*® website that relate to the themes of the ESD KitS. You can search on the *Scratch*® website using terms such as "wind power," "water quality," or "renewable energy" and you will find many more.

You can search for Projects or Studios. A *Scratch*® Studio is a collection of Projects that are related to each other in some way. Any *Scratch*® user can set up a Studio. If you search for "renewable energy" you will see Projects related to that theme. If you click the Studios tab, you will see Studios with collections of Projects on that theme. If you click on one of them, you will see the Projects in that Studio.

Wind Power

https://scratch.mit.edu/projects/15858581/
This is an interactive report on wind power and other sources of energy used to produce electricity.

Wind Power Grids

https://scratch.mit.edu/projects/718595

An overview of US Wind Power electric power grids.

The Story of Energy

https://scratch.mit.edu/projects/1021089

This interactive story of energy includes four games focused on using renewable energy sources and reducing energy consumption.

Solar Panel

https://scratch.mit.edu/projects/11732/

This *Scratch*® project presents the case for increased use of solar panels to generate electricity.

Protect our water quality!

https://scratch.mit.edu/projects/437778501/

This animated tutorial on water quality is followed by a brief quiz.

Water Quality

https://scratch.mit.edu/projects/299820109/

This is an interactive presentation about water quality with a quiz at the end.

ESD KIT:
IMPACTS OF CLIMATE CHANGE

Sustainable Development Goal 13: Climate Action

APPENDIX 2: ABOUT MICRO:BIT

The micro:bit is a microcontroller that connects with a wide range of sensors and output devices and is programmed by connecting it to a laptop, tablet, or smartphone. It is designed for use in education and is widely available in many countries. Visit the micro:bit Foundation website at **https://microbit.org/** for all the information you need to get started. Click the Get Started tab on the homepage for tutorials on how to set up and program the micro:bit. To obtain a micro:bit, click the Buy tab on the homepage to locate a distributor in your country.

For activities that include data logging, you will need a micro:bt V2, which is the current version. To become familiar with how data logging works, go to **https://microbit.org/get-started/user-guide/data-logging/.**

The micro: bit is a good choice for ESD Kit Investigations and projects for several reasons. It is

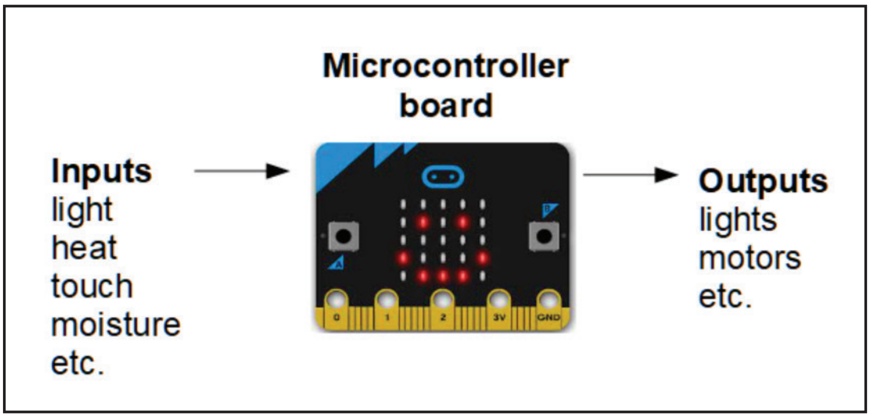
1. designed for education and has extensive support for teachers and students,
2. relatively low cost, and
3. widely available around the world.

Also, micro:bit has sensors built into the board itself, including temperature and light. Additional external sensors may be connected to it. The current version (V2) can be used for data logging.

An alternative to micro:bit is Arduino **https://www.arduino.cc/**, a family of similar microcontrollers. They are also widely available and well-supported.

More About Microcontrollers

A microcontroller is a device that takes inputs from sensors and acts upon them to control various devices. They are found in many appliances including microwave ovens, heating and cooling units, and automobiles.



Credit: Logo Foundation

Here are some examples of how a microcontroller can be used with sensors and output devices:

Light sensor ► turn lights on at night, off during the day

Temperature sensor ► turn a fan on when it's hot, off when it's cool

Moisture sensor ► turn irrigation water on when the ground is dry; off when moist

Microcontrollers can also be used to record sensor data over time. For example, you could record temperature at one-minute intervals over a period of 24 hours and then use the data in a graph or other visual representation.