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The EcoMystery Project:

Interactive Escape Rooms for Climate Crisis
Awareness and Civic Engagement in School Education

WP3

Escape the Climate Crisis Coursework Module 3: Climate Science Experiments

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Module 3: Climate Science Experiments

The EcoMystery Project: Interactive Escape Rooms for Climate Crisis Awareness and Civic Engagement in School Education

(2024-1-IT02-KA220-SCH-000248873)

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Module 3: Climate Science Experiments

Table of Contents

Module 3: Climate Science Experiments	4
Introduction.....	4
Learning Objectives.....	5
Time Required	6
Unit 1 - Temperature Measurement, Temperature Mapping	7
Thermal Expansion	8
The Effect of Temperature on Electrical Resistance	11
How to Measure Air Temperature Correctly.....	13
Non-contact Temperature Measurement	14
Unit 2 - Earth's Energy Balance	16
Albedo.....	17
The Greenhouse Effect.....	18
Unit 3 - Ocean Acidification.....	20
Acidification of water	20
What does pH represent	21
Measuring pH.....	22
Unit 4 - Ice Melting	24
Contribution to Sea Level Rise.....	24
Archimedes' Principle.....	24
Consequences for Sea Level	25
The Effect of Glaciers on the Salinity of Seawater	25



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Module 3: Climate Science Experiments

The Effect of Glacier Melting on Ocean Currents	26
Classroom Activities.....	28
Activity 1 - Thermal Expansion: Investigating How Temperature Affects the Volume of Water.....	28
Activity 2 – Albedo: Investigating How Different Surfaces Reflect (and Absorb) Solar Radiation	37
Activity 3 - The Greenhouse Effect: Investigating How the Atmosphere Influences the Earth's Temperature.....	46
Activity 4 - Water Acidification: Investigating How Carbon Dioxide Dissolves in Water and Its Effects on the Calcium Carbonate Shells of Marine Organisms	56
Activity 5 - Temperature Map of the School Surroundings / Town.....	65
Activity 6 - Glacier Melting	75
References	88



Module 3: Climate Science Experiments

Introduction

Experiments are critically important in climate change education for primary and secondary students because they transform abstract, complex scientific concepts into tangible, relatable, and engaging learning experiences.

Experiments engage students in the practices of science - students learn to **formulate hypotheses, collect and analyse data** (e.g., measuring temperature), and **draw evidence-based conclusions**. Development of science process skills helps them later to **evaluate complex information and differentiate between scientific fact and misinformation related to climate change**.

A broader framework for understanding the meaning of experiments and their use in education is provided by the Inquiry-Based Science Education approach (IBSE). IBSE is defined as a teaching process that involves exploring the world and that leads to asking questions, making discoveries, rigorously testing discoveries, and seeking new understanding. It should be as close as possible to the process of true science. (Main, 2026).

The process of inquiry should be initiated and stimulated by intrinsic curiosity, wonder, and an interest in understanding what is observed or solving a problem. It begins when a learner notices something striking, surprising, or new that does not make sense in relation to his or her previous experiences or current understanding. It continues by observing, asking questions, making predictions, testing hypotheses, and developing theories and conceptual models. Making sense of the experiences gained requires reflection, conducting interviews, comparing one's own results with those of others, interpreting data, and applying newly developed concepts in other contexts. Inquiry-based science education strengthens scientific literacy and builds trust in science.



Module 3: Climate Science Experiments

Inquiry and experimentation enable more immersive experience, move students beyond rote memorization to deeper conceptual understanding, develop critical thinking and personal engagement. At the same time, they promote teamwork which enhances collaboration and communication skills as students work together to interpret results and discuss implications.

Although climate change involves complex global processes, key concepts can be demonstrated using simple models as well as out-of-school measurements:

- Observations and measurements in real-life environments that are familiar and relevant to students, such as creating a local temperature map, demonstrate that climate change is happening here and now and affects all of us. These activities aim to show that the decisions we make in our everyday lives also matter.
- Visual models, such as comparing changes in water level caused by the melting of land ice and sea ice, directly demonstrate the real consequences of climate change while helping students understand the underlying scientific concepts.

Focusing activities on solutions empowers students, giving them a sense of agency—the belief that their actions can make a difference rather than just feeling overwhelmed or anxious by the scale of the problem

Learning Objectives

Experimentation fosters the development of all key 21st-century skills (Kennedy et al., 2020). During the planning phase of an experiment, students primarily develop initiative, creativity, and critical thinking. Conducting experiments collaboratively promotes teamwork, communication, leadership, and adaptability. Collecting, analysing, and interpreting data primarily strengthens digital and information literacy, critical thinking, and productivity. Presenting results further supports the development of social skills, creativity, communication, and media literacy.



Module 3: Climate Science Experiments

The goal of climate change education extends beyond developing conceptual understanding of selected concepts and phenomena. The activities proposed in this module are also designed to foster students' understanding of the nature of science, develop the skills required for engaging in scientific inquiry, and promote informed attitudes towards science (Harlen, 2015).

Although this module can be implemented as a complete unit, it has been designed to provide teachers with the flexibility to use only selected activities in their teaching. Therefore, specific learning objectives are provided for each activity individually. These objectives can also be adapted to reflect the characteristics of the target group, including students' prior knowledge and their previous experience with IBSE

Time Required

This module has been designed so that it can be used either as a coherent unit or implemented gradually through individual activities. The proposed activities are intended to complement and deepen students' understanding of the concepts introduced in Module 1 – Why Is Our Climate in Crisis? and Module 2 – How Will the Climate Change? Therefore, the estimated duration is provided at the beginning of each activity.

In general, the activities have been designed so that their core version can be completed within a 45-minute lesson. If a teacher chooses to implement an activity as a field investigation, additional time should be allocated for travelling to the measurement site and returning to the classroom.



Unit 1 - Temperature Measurement, Temperature Mapping

Monitoring climate change involves measuring not only air temperature but also the temperature of oceans and seas. Measuring temperature at the same locations over many years makes it possible to observe changes in the Earth's climate. In this way, scientists can determine whether the average temperature is increasing or decreasing.

In addition, information about air temperature helps us understand and forecast weather, protect human health, plan activities, and monitor changes in the natural environment:

1. Weather forecasting – Meteorologists measure temperature at agreed times at many locations around the world. The collected data are used to monitor changes in weather patterns and the movement of warm and cold air masses. These measurements help meteorologists forecast weather conditions and issue warnings about extreme weather events such as heatwaves and severe frosts.
2. Health protection – Extreme temperatures can pose risks to human health. High temperatures may lead to overheating or heat stroke, whereas low temperatures may cause hypothermia. Temperature measurements enable authorities to issue warnings about hazardous weather conditions, allowing people to adapt their planned activities and reduce potential risks.
3. Agriculture – Air and soil temperatures influence seed germination and crop development. When meteorologists issue warnings about spring frosts, farmers can take measures to protect crops. For example, blossoming fruit trees can be protected from frost by smoke generation, misting, or sprinkler irrigation.
4. Transport – At low temperatures, frost and ice may form on roads as well as on aircraft surfaces. It is therefore necessary to prepare technical measures in



Module 3: Climate Science Experiments

advance to reduce or eliminate the risk of icing. High temperatures can also cause problems, particularly in railway transport, where rails may expand and deform, potentially leading to train derailments.

When measuring temperature, we are in fact observing the effect of temperature on a particular physical property.

A thermometer does not measure temperature directly. Instead, it measures a change in a physical property that depends on temperature. For example, a liquid-in-glass thermometer uses the dependence of a liquid's volume on temperature, a digital thermometer may use the temperature dependence of the electrical resistance of a sensor, and an analogue dial thermometer may use changes in the length and curvature of a bimetallic strip.

Before a thermometer can provide an accurate reading, it must either absorb thermal energy from its surroundings and warm up or transfer energy to its surroundings and cool down. To measure temperature correctly, it is therefore necessary to wait until thermal equilibrium is established, that is, until the thermometer reaches the same temperature as its surroundings. This is indicated by the thermometer reading becoming stable.

Thermal Expansion

Thermal expansion is a phenomenon in which the volume or dimensions of an object change because of a change in temperature. When heated, most substances expand, meaning that their volume increases. Conversely, when cooled, most substances contract and their volume decreases. This behaviour is a consequence of the particulate structure of matter. All matter consists of very small particles – atoms or molecules. These particles are in constant motion. In solids, they vibrate around their equilibrium positions, whereas in liquids they move relative to one another and can travel throughout the entire volume of the liquid because they are not fixed in place.

Module 3: Climate Science Experiments

As a substance is heated, its particles gain kinetic energy and move more rapidly. In solids, the amplitude of the particles' vibrational motion increases, while in liquids the particles can more easily overcome the attractive forces acting between them. As a result, the average distance between particles increases, causing most substances to expand as temperature rises. (Importantly, the atoms themselves do not become larger.)

Solid materials also change their volume when the temperature changes. For objects with a suitable shape (e.g. a thin wire, strip, or railway rail), this change in volume is observed as a change in length.

Dive Deeper!

The relationship is given by: $l = l_0 \cdot (1 + \alpha \cdot \Delta t)$, where l is the final length of the strip, l_0 is its initial length, α is the coefficient of linear thermal expansion (a material property) and $\Delta t = t - t_0$ is the temperature change, i.e. the difference between the final temperature (t) and the initial temperature (t_0) of the metal strip.

If the strip consists of two different metals with different coefficients of linear thermal expansion (a bimetallic strip), each metal expands by a different amount when the temperature changes. As a result, the strip bends, and this bending can be observed through the movement of a pointer.

Module 3: Climate Science Experiments

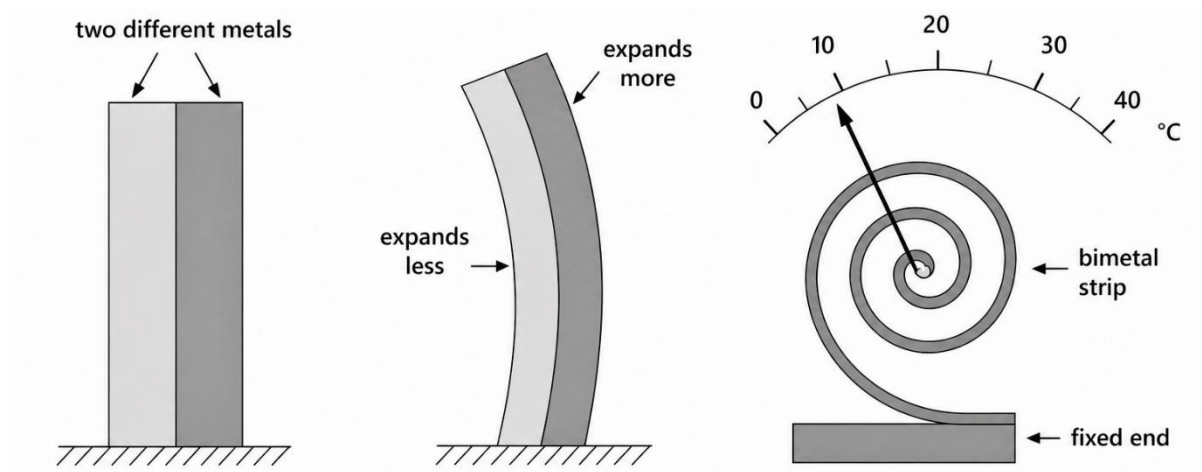


FIGURE 1. PRINCIPLE OF TEMPERATURE MEASUREMENT USING A BIMETALLIC STRIP

A liquid-in-glass thermometer contains a thin tube filled with a liquid. When the liquid is heated, its volume increases and the liquid level in the tube rises. The magnitude of the volume change depends on the type of liquid (specifically, on its coefficient of volumetric thermal expansion) and on the temperature change.

Dive Deeper!

The relationship is given by $V = V_0 \cdot (1 + \beta \cdot \Delta t)$, where V is the final volume of the liquid, V_0 is the initial volume, β is the coefficient of volumetric thermal expansion (a material property) and $\Delta t = t - t_0$ is the temperature change, i.e., the difference between the final (t) and initial (t_0) temperatures of the liquid.

Mercury and alcohol expand as their temperature increases. Water also generally expands when heated. However, an exception occurs when water is heated between 0 °C and 4 °C, during which its volume decreases. This phenomenon is known as the anomalous expansion of water and is related to the hydrogen bonds between water molecules. In ice (solid water), these bonds form an open crystalline structure with



Module 3: Climate Science Experiments

relatively large spaces between the molecules. As a result, ice has a lower density than liquid water. When water is heated from 0 °C to 4 °C, the breakdown of this open structure predominates, reducing the distance between water molecules and causing the volume of a given amount of water to decrease. Above 4 °C, the increasing kinetic energy of the molecules becomes the dominant effect, increasing the distance between them and causing the water to expand. Consequently, water reaches its maximum density at approximately 4 °C, a property that enables aquatic organisms to survive during winter, while ice remains less dense than liquid water and therefore floats on its surface.

One of the consequences of climate change and the rising average temperature of the oceans is the increase in seawater volume due to thermal expansion.

The Effect of Temperature on Electrical Resistance

Most digital thermometers make use of the dependence of the electrical resistance of an electronic component on temperature. Electrical resistance is a physical quantity that describes how strongly an electrical component opposes the flow of electric current. The greater the resistance, the smaller the electric current that passes through the component for a given voltage.

In metals, a rise in temperature causes an increase in both the speed and amplitude of the movement of metal atoms around their equilibrium positions. Consequently, the electrical resistance of metal components increases as the temperature rises.

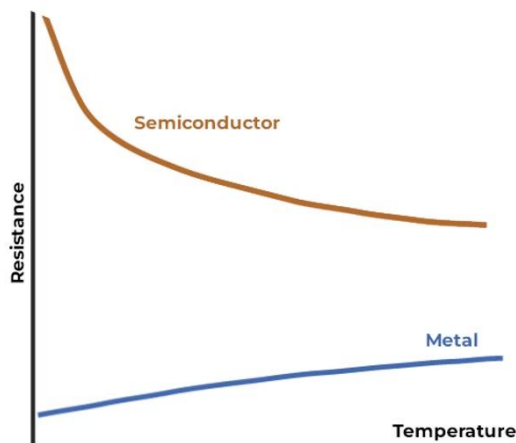
Module 3: Climate Science Experiments

Dive Deeper!

The relationship can be expressed as $R = R_0 \cdot (1 + \gamma \cdot \Delta t)$, where R is the final resistance of the metallic component, R_0 is its initial resistance, γ is the temperature coefficient of resistance and $\Delta t = t - t_0$ is the temperature change, i.e., the difference between the final (t) and initial (t_0) temperatures of the component.

semiconductors, increasing temperature causes some electrons to gain enough energy to break free from the bonds between atoms. This results in an increase in the number of free charge carriers and, consequently, a decrease in the electrical resistance of the semiconductor component.

Therefore, temperature affects the electrical resistance of metals and semiconductors in fundamentally different ways.





Module 3: Climate Science Experiments

How to Measure Air Temperature Correctly

If a thermometer used to measure air temperature were exposed to direct sunlight, solar radiation would heat the thermometer itself, causing it to display a higher temperature than the actual air temperature. This is because the Sun primarily heats the Earth's surface (and other solid materials), while the air is subsequently warmed by conduction, convection, and infrared radiation emitted by the surface. The direct heating of air by solar radiation is relatively small. Similarly, air temperature measurements can be distorted if they are taken near a building wall, above asphalt or rooftops, or close to a radiator or another heat source.

Teaching Tip!

If we want to compare air temperatures measured at different locations around the world, it is important that measurements are made under the same conditions. Meteorologists have therefore established the following guidelines for accurate air temperature measurements:

- the thermometer should be placed in the shade,
- the thermometer should be positioned approximately 2 metres above the ground,
- the thermometer should be located above grass rather than concrete or asphalt,
- air should be able to circulate freely around the thermometer.

At meteorological stations, thermometers are placed inside a white-painted weather shelter to prevent direct heating by solar radiation. The walls of the shelter are made of thin slats that allow air to circulate while shielding the thermometer from direct sunlight (MetLink, n.d.).



Module 3: Climate Science Experiments

When a thermometer is brought to a measurement site, it may initially have a different temperature from the surrounding air whose temperature is to be measured. Heat exchange occurs between the air and the thermometer until thermal equilibrium is reached. This process may take several minutes. Once the thermometer reading stabilizes, the temperature can be read and recorded.

Non-contact Temperature Measurement

The temperature of an object can also be measured without direct contact. An infrared (radiation) thermometer determines temperature from the electromagnetic radiation emitted by the object's surface. As an object's temperature increases, the wavelength at which it emits the greatest amount of radiation becomes shorter. The thermometer detects this radiation, converts it into an electrical signal, and its electronics calculate the object's temperature.

Unlike contact thermometers, infrared thermometers do not need to reach thermal equilibrium with the object being measured. Consequently, temperature measurements can be obtained much more rapidly.

The software in an infrared thermometer assumes that most of the radiation detected by the sensor originates from the measured object. This assumption is valid for surfaces with high emissivity, such as wood, paper, skin, or matte black surfaces, which emit thermal radiation efficiently. In contrast, shiny metals behave similarly to mirrors in visible light—they reflect a large proportion of the thermal radiation incident upon them from their surroundings. As a result, the thermometer detects not only the radiation emitted by the metal itself but also radiation reflected from nearby objects. If the metal surface is highly polished, its own thermal emission is relatively low, and most of the detected radiation originates from the surroundings. This may lead to falsely high temperature readings if the metal reflects radiation from a hot radiator, or falsely low readings if it reflects the weak thermal radiation from a cold window. By



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contrast, a dark, matte surface has high emissivity and reflects only a small proportion of the surrounding thermal radiation, resulting in more accurate temperature measurements (FLIR, 2021).

Infrared thermometers can also be used to investigate the effect of different surface materials (e.g. asphalt and grass) on temperature. Such measurements help students understand the formation of the urban heat island effect.



Unit 2 - Earth's Energy Balance

The Earth's energy balance refers to the comparison between the energy that the Earth receives and the energy that it emits back into space. For the Earth to remain in equilibrium, the average amount of energy entering the Earth system through the top of the atmosphere must equal the average amount of energy escaping through the top of the atmosphere into space.

Of the incoming solar radiation reaching the Earth, a portion (approximately 30%) is reflected into space, primarily by clouds, snow, ice, and bright surfaces. The quantity describing this phenomenon is called albedo (reflectivity). A smaller fraction of the incoming solar radiation (approximately 20%) is absorbed by the atmosphere, while about half of it (almost 50%) reaches the Earth's surface, where it is absorbed and causes the surface to warm (Lindsay, 2009).

Like any warm object, the Earth's surface emits energy after being heated. However, the radiation emitted by the Sun and that emitted by the Earth's surface differ in their characteristics, particularly in their wavelengths. Radiation emitted by the Earth's surface has a longer wavelength and lies in the infrared region of the electromagnetic spectrum. Compared with the Sun's shortwave radiation, this longwave infrared radiation is absorbed to a much greater extent by greenhouse gases in the atmosphere. The warmed atmosphere then re-emits energy in all directions, including a substantial portion back towards the Earth's surface. As a result of this natural greenhouse effect, the Earth's average surface temperature is approximately 15 °C rather than about -18 °C, which would be expected in its absence (NASA, 2024).

When the total amount of incoming energy equals the total amount of outgoing energy on average, the Earth's energy balance is in equilibrium, and the planet's average temperature remains relatively stable. If, on average, the Earth emits less energy than it receives, excess energy accumulates within the climate system, causing the Earth's



Module 3: Climate Science Experiments

average temperature to rise. Conversely, if the Earth were to emit more energy than it receives, the average global temperature would decrease.

Albedo

Albedo is a physical quantity that describes how a surface interacts with electromagnetic radiation. It represents the fraction of incoming solar radiation that is reflected by a surface.

Dive Deeper!

In this context, albedo primarily refers to the reflection of visible and near-infrared solar radiation. It is defined as the ratio of reflected radiation to incoming radiation and ranges from 0 (no reflection) to 1 (all incoming radiation is reflected).

For example, fresh snow has a high albedo (0.70–0.95), meaning that it reflects most incoming sunlight and therefore warms only slightly. In contrast, the ocean surface has a low albedo when sunlight strikes it nearly perpendicular to the surface (e.g. around midday), with a value of approximately 0.05. Under these conditions, the ocean reflects only a small fraction of the incoming solar radiation, absorbs most of it, and consequently warms up (ESA, 2013), (UCAR, n.d.).

As rising temperatures cause snow and ice to melt, their highly reflective surfaces are replaced by land or open water, which have much lower albedo. These darker surfaces reflect less solar radiation and absorb more energy, leading to further warming. This process is one of the main reasons why temperatures in the Arctic have been increasing approximately two to four times faster than the global average.



Module 3: Climate Science Experiments

The Greenhouse Effect

A large proportion of solar radiation passes through the Earth's atmosphere, reaches the Earth's surface, and warms it. The warmed surface then emits infrared radiation. This radiation does not escape completely into space because several gases in the atmosphere absorb part of it. As a result, the atmosphere warms and subsequently re-emits this energy, including back towards the Earth's surface.

The term greenhouse effect is based on an analogy with a greenhouse. Glass readily transmits visible solar radiation, which is absorbed by the soil inside the greenhouse, causing it to warm up. The warmed soil heats the air. The greenhouse prevents the warmed air from flowing away. As a result, the temperature inside the greenhouse increases.

In reality, greenhouse gases do not prevent the movement of warm air. The term refers to gases in the atmosphere that have an increased ability to absorb infrared radiation. The most important greenhouse gas in the Earth's atmosphere is water vapour. It retains the greatest amount of heat. However, climatologists are more concerned about other greenhouse gases, such as carbon dioxide and methane, whose concentrations in the atmosphere have been significantly affected by human activities and have been increasing since the beginning of the Industrial Revolution (ESA, n.d.). Greenhouse gases subsequently re-emit the absorbed infrared radiation in all directions, including back towards the Earth's surface. As a result, less heat escapes into space and the Earth's temperature increases.

Clouds, which consist of water, absorb part of the infrared radiation emitted by the Earth's surface. They then re-emit the absorbed energy, including back towards the Earth's surface. Consequently, temperatures decrease less during cloudy nights than under clear night skies. An increase in air temperature also increases the atmosphere's capacity to hold water vapour. One consequence of the increase in the Earth's average



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temperature is therefore an enhancement of the greenhouse effect, leading to further warming.

If the Earth's atmosphere contained no greenhouse gases, solar radiation would warm the lower atmosphere to an average temperature of -18°C rather than approximately 15°C , which is the current global average. Conversely, increasing concentrations of greenhouse gases in the atmosphere, for example through human emissions of carbon dioxide, reduce the amount of heat escaping into space and lead to an increase in the Earth's average temperature.



Module 3: Climate Science Experiments

Unit 3 - Ocean Acidification

Increasing human emissions of carbon dioxide do not only increase the concentration of greenhouse gases in the atmosphere. As the concentration of carbon dioxide in the air rises, the amount of carbon dioxide dissolved in water also increases. As a result, the chemical properties of water change.

Acidification of water

Carbon dioxide present in the atmosphere interacts with water and partially dissolves in it. This process is described by Henry's law: At constant temperature, the concentration of a gas dissolved in a liquid is directly proportional to the partial pressure of that gas above the liquid.

Dive Deeper!

When carbon dioxide dissolves in water, several chemical reactions take place:

- Carbon dioxide reacts with water to form carbonic acid: $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$
- Carbonic acid partially dissociates: $\text{H}_2\text{CO}_3 \rightarrow \text{H}^+ + \text{HCO}_3^-$
- Hydrogen ions react with carbonate ions: $\text{H}^+ + \text{CO}_3^{2-} \rightarrow \text{HCO}_3^-$

As a result, the concentration of carbonate ions in the water decreases. These ions are required for the formation of calcium carbonate (CaCO_3), the material from which the shells and skeletons of many marine organisms are made (MetLink, n.d.).

A decrease in the pH of seawater leads to a reduction in the availability of carbonate ions, affecting marine ecosystems. For example, corals, shellfish, sea snails, sea urchins, and some species of plankton grow more slowly when carbonate ions are



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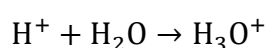
scarce, and their shells and skeletons become thinner and more vulnerable to damage. As a consequence, marine food webs plankton → small fish → large fish → marine mammals are disrupted, and biodiversity declines.

When explaining ocean acidification, it is important to emphasize that seawater has a pH of approximately 8.1 and is therefore slightly alkaline. A decrease in pH of 0.1 does not make seawater acidic; however, it increases the concentration of hydrogen ions by approximately 30%. This substantially alters the chemical environment of the oceans and makes it more difficult for marine organisms to build calcium carbonate shells and skeletons (NOAA, n.d.).

In addition to the effect of increasing atmospheric carbon dioxide concentrations, increasing temperature also plays a role. Higher temperatures reduce the solubility of gases in liquids. As temperature increases, molecules have greater kinetic energy, making it easier for gas molecules to escape from the liquid. Consequently, warming oceans could slightly reduce ocean acidification by decreasing the amount of dissolved carbon dioxide. However, this effect is much weaker than the effect of increasing atmospheric carbon dioxide concentrations.

What does pH represent

One of the most important chemical characteristics of aqueous solutions is the concentration of hydrogen ions. Hydrogen ions are positively charged hydrogen atoms that have lost their only electron. Consequently, a hydrogen ion consists only of a hydrogen nucleus, which contains a single proton. In aqueous solutions, hydrogen ions react almost immediately with water molecules to form hydronium ions



A high concentration of hydrogen ions results in a stronger acidic taste, and the solution is described as more acidic. The concentration of hydrogen ions is expressed



Module 3: Climate Science Experiments

by the quantity pH. A high concentration of hydrogen ions corresponds to a low pH, whereas a low concentration corresponds to a high pH.

The pH scale ranges from 0 to 14:

- solutions with $\text{pH} < 7$ are acidic (for example, the term *acid rain* refers to precipitation with a pH below 5.6);
- a solution with $\text{pH} = 7$ is neutral (pure water at 25 °C);
- solutions with $\text{pH} > 7$ are alkaline (basic) (for example, the average pH of seawater is approximately 8.1, meaning that seawater is slightly alkaline).

The pH scale is logarithmic. The difference of one pH unit corresponds to a tenfold change in hydrogen ion concentration, while the difference of two pH units corresponds to a hundredfold change.

Measuring pH

Several methods are available for measuring pH. One of the most common is the use of indicator paper. The paper is briefly immersed in the solution and then removed. The resulting colour change is compared with the accompanying colour chart. Indicator papers are available either for specific pH ranges or as universal indicators (a mixture of several indicators). Measuring pH with indicator paper is simple and rapid but provides only approximate values.

Typical colours of a universal indicator are:

- red – strongly acidic,
- orange to yellow – acidic,
- green – neutral,
- blue – alkaline,
- purple – strongly alkaline.



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More accurate measurements can be obtained using an electronic pH meter. Its operating principle is based on measuring the electrical potential difference between a measuring electrode, which interacts with hydrogen ions in the solution, and a reference electrode.

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Unit 4 - Ice Melting

Contribution to Sea Level Rise

Water is one of the substances whose density decreases during the transition from the liquid to the solid state. This is because water molecules form an ordered structure as water freezes. This results from the formation of hydrogen bonds, which are weak intermolecular forces between a hydrogen atom in one water molecule and an oxygen atom in another water molecule. As this ordered structure forms, the volume of water increases during freezing. Since the mass of the water remains unchanged, its density decreases.

The physical quantity density is defined by the relationship:

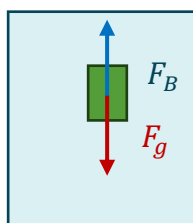
$$\rho = \frac{m}{V}$$

Therefore, if the volume V increases while the mass m remains constant, the density ρ must decrease.

The difference between the density of a solid object and the density of the liquid determines the position in which the object comes to rest in the liquid. If the object (in this case, ice) has a lower density than the liquid (in this case, water), it will float. This behaviour is described more precisely by Archimedes' principle.

Archimedes' Principle

A body immersed in a liquid experiences an upward buoyant force equal to the weight of the liquid displaced by the submerged part of the body.





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If the density of the body is lower than the density of the liquid, the gravitational force acting on the body is smaller than the buoyant force (equal to the weight of the displaced liquid), and the body rises towards the surface after being immersed. The upward motion stops when the weight of the liquid displaced by the submerged part of the body is equal to the weight of the entire body. If the body is ice, this means that when it melts, it produces exactly the same volume of liquid water as the volume of its submerged part.

Consequences for Sea Level

When ice located on land melts, the resulting liquid water flows into the oceans, causing sea level to rise. In contrast, when floating sea ice melts, it does not change the sea level. This does not mean, however, that the melting of sea ice has no impact on ecosystems.

While the melting of Arctic sea ice does not directly contribute to sea level rise because it is already floating, the melting of glaciers and ice sheets in Antarctica does increase sea level, as this ice is located on land.

The Effect of Glaciers on the Salinity of Seawater

A phase change of pure water from the solid to the liquid state occurs at 0 °C under normal atmospheric pressure (101.3 kPa at sea level). When salts are dissolved in water, the temperature at which the phase change occurs is lower, and its exact value depends on the concentration of dissolved substances. For example, seawater with an average salinity of 3.5% freezes at approximately -1.9 °C (Graham, Johnston, & Nicholson, 1992). The ice that forms is considerably less saline than the surrounding seawater.



Module 3: Climate Science Experiments

As seawater cools, its temperature decreases until it reaches the point at which liquid water begins to freeze. At the onset of freezing, sea ice forms, containing small cavities between the ice crystals filled with highly concentrated saline solution (brine) (Villarroel, Zuazagoitia, 2016). As the ice continues to grow and seawater moves around it, this brine is gradually expelled from the ice into the surrounding water. As a result, the salinity of seawater increases in regions where sea ice is forming. The melting of sea ice has the opposite effect, reducing the salinity of seawater.

If a saline solution freezes without any movement, for example in a container placed in a freezer, the concentrated brine is not washed out, and most of it remains trapped between the ice crystals. The resulting ice has a brittle structure, with cavities between its layers filled with saline solution. If the temperature becomes sufficiently low (the exact temperature depends on the salt concentration), the trapped saline solution eventually freezes as well.

The Effect of Glacier Melting on Ocean Currents

Archimedes' principle, introduced in Section 4.4.1, applies not only to solid bodies immersed in liquids but also to liquids with different densities. It can easily be demonstrated that immiscible liquids with different densities (for example, water and oil) form separate layers. The liquid with the lower density floats on top of the liquid with the higher density. If the liquids are miscible (for example, when fruit syrup is poured into a glass of water), the layers are not clearly separated, and mixing may even eliminate the density differences (for example, by stirring the water and syrup with a spoon).

Water reaches its maximum density at approximately 3.9 °C. At lower temperatures, hydrogen bonds between water molecules begin to form, causing the molecules to arrange into a more ordered structure and leading to a gradual decrease in the density of liquid water between 3.9 °C and 0 °C (until freezing occurs). As a result, water



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Module 3: Climate Science Experiments

freezes from the surface downward. At temperatures above 4 °C, warmer water has a lower density than colder water.

Ocean water is heated by incoming solar radiation. Because sunlight reaches the ocean surface at different angles depending on latitude and season, the heating of seawater is uneven. If no other factors were involved, warm surface currents would flow from the equatorial regions towards the poles, while cold deep-water currents would flow from the poles towards the equator.

An important factor influencing ocean currents is the salinity of seawater. The higher the salt concentration, the greater the density of seawater. Water with a higher salt content therefore sinks to greater depths. However, when glaciers melt in regions where ice was previously forming, salinity decreases instead of increasing. Consequently, the density of seawater is reduced, and the water remains near the surface. This creates a problem because the main circulation system of the Atlantic Ocean depends on cold, dense, saline water sinking near the poles, while warm water from tropical regions flows in to replace it. This large-scale heat transport plays a key role in regulating the climate of the entire Northern Hemisphere. The melting of glaciers in the Arctic and Greenland increases the input of freshwater into the North Atlantic. This reduces the salinity and density of surface waters and may weaken the Atlantic Meridional Overturning Circulation (AMOC), an important component of the global thermohaline circulation. Because the AMOC transports heat between the tropics and higher latitudes, its weakening may affect both climate and marine ecosystems in many parts of the world. (NASA, 2023)

The warming of the ocean surface is also influenced by heat exchange between the ocean and the atmosphere.

Module 3: Climate Science Experiments

Classroom Activities

Activity 1 - Thermal Expansion: Investigating How Temperature Affects the Volume of Water

Subject or subjects	Science Physics Environmental Education Mathematics (reading the measured values, chart creation)
Age/Level	10 – 12 years, lower secondary education (ISCED 2)
Time required	30 minutes in the qualitative observation version 45 minutes in the quantitative experiment version
Learning goals	Students can plan an experiment in collaboration with others. Students can record experimental data. Students can interpret the results of the experiment. Students find that heating a liquid increases its volume. Students can transfer the experimental findings to a new context. Student: - observes the change in the volume of a liquid when heated and cooled,

Module 3: Climate Science Experiments

	- describes in their own words the thermal expansion of liquids, - explains that most liquids expand when heated and contract when cooled, - records the results of the observation and draws simple conclusions, - gives an example of a practical application of the thermal expansion of liquids (e.g. a liquid thermometer).
Prior knowledge & skills	No prior knowledge is required for qualitative observation. For the quantitative experiment, it is assumed that students are familiar with the concepts of temperature and thermometer. In both versions, it is assumed that students know how to handle hot water and simple laboratory equipment safely. Students can observe a phenomenon and record the results in a table. Students can compare values and formulate a simple conclusion. If students have sufficient manual skills, they can construct their own experimental apparatus.
Materials, resources & settings	- A jar with a lid, or a transparent glass or plastic bottle with a cap, or a cork or rubber stopper, - a thin transparent tube (ideally, a glass capillary is used, but the phenomenon can also be observed with a transparent straw),

Module 3: Climate Science Experiments

- *plasticine or sealant,*
- *colored water,*
- *two containers (deeper bowls into which the jar or bottle can be placed),*
- *warm water (approximately 50 °C - 60 °C),*
- *cold water or water with ice,*
- *in the case of a quantitative experiment, a thermometer to measure the water temperature,*
- *a ruler (optional)*
- *a worksheet (optional).*

Preparation: in the jar lid or the bottle stopper, it is necessary to drill a hole in advance with the same diameter as the diameter of the transparent tube used. For the quantitative experiment it is necessary to drill two holes in the lid of the container – for a transparent tube and for a thermometer. The tube and the thermometer must be sealed in the lid so that water does not leak out of the container around them.

A science or physics classroom adapted for group work.

Activity description

1. Problem statement:

How does the volume of water change when its temperature changes?

Students formulate a simple prediction, for example: If water is heated, its volume will increase.

2. Observation, experiment:

- *Fill the container (jam jar/bottle) to the brim with colored water.*

Module 3: Climate Science Experiments

- Close the container with a lid (or stopper) through which a transparent tube is inserted so that the water rises into the tube.
- Mark the initial height of the water level in the tube.
- Place the bottle in a bowl of warm water. Observe the change in the height of the colored water in the tube.
- Place the bottle in cold water and observe the change in the height of the colored water in the tube.

3. Recording the observation:

Students organize their observations (measurement results) in a table:

Conditions	Position of water level
Before temperature change	
After immersion in warm water	
After immersion in cold water	

Students can record the change in level verbally or measure it with a ruler.

In the case of a quantitative experiment, students write the temperature of the colored water in the "Conditions" column, and at least 5 different values are expected to be recorded.

4. Discussion

The teacher can support the interpretation of the observation and the formulation of the conclusion by asking the questions such as with questions:

What happened to the water level in the tube when it was heated?

What happened when it was cooled?

Does the increase in water level mean that there was more water in the container with the tube?



Module 3: Climate Science Experiments

How can the experimental setup be modified to make the change in water level larger?

5. Students formulate the conclusion together.

For example: The volume of some liquids increases when they are heated and decreases when they are cooled. This phenomenon is called thermal volumetric expansion of liquids.

6. Application

- Thermal volumetric expansion of liquids is used to measure temperature with liquid thermometers
- Thermal volumetric expansion of liquids contributes to sea-level rise as the oceans are heated.

Accessibility & Inclusion

To ensure that the activity is inclusive and accessible to all learners, students can work in small heterogeneous groups with clearly assigned roles (e.g. handling equipment, observing changes in the liquid level, recording observations, presenting conclusions). Instructions should be provided both verbally and in written form, supported by images or a diagram of the experimental setup.

References Bibliography

Harlen, W. (2015). *Working with Big Ideas of Science Education*. Science Education Programme of IAP.

NASA (2024, Nov. 5). *Thermal Expansion Model*. Jet Propulsion Laboratory NASA.
<https://www.jpl.nasa.gov/edu/resources/lesson-plan/thermal-expansion-model/>

Assessment

Module 3: Climate Science Experiments

Formative Assessment	<i>During the activity, the teacher observes:</i> - the formulation of the hypothesis, - the correctness of the experimental procedure, - work safety, - cooperation in the group, - ability to interpret the results. <i>The teacher may use guiding questions such as:</i> - What are you observing at the moment? - Was your hypothesis confirmed? - How do you explain the change in the water level?
Summative Assessment (if applicable)	<i>The teacher can assess:</i> - completeness and correctness of the worksheet, - explanation of the principle of the liquid thermometer.
Student Self-Assessment	<i>At the end of the lesson, students will complete statements such as:</i> - Today I learned... - What surprised me most was... - Next time I would like to improve... <i>Alternatively, students may indicate their level of understanding using a self-assessment scale:</i>



Module 3: Climate Science Experiments

	☐ <i>I understand completely.</i> ☐ <i>I understand with a little help.</i> ☐ <i>I need further explanation.</i>
Peer Feedback	<i>Each group briefly presents their results. Other students may provide feedback by considering questions such as:</i> • <i>What was particularly clear in the presentation?</i> • <i>What did you find interesting?</i> • <i>What question would you ask the group?</i>
Documentation, Evidence & Follow-Up	
Evidence to Collect	- <i>Worksheets,</i> - <i>student hypotheses,</i> - <i>observation/measurement tables,</i> - <i>photographs of the experiment.</i>
Impact Tracking	<i>The teacher monitors whether the students:</i> - <i>understand the relationship between temperature and volume of a liquid,</i> - <i>can explain the principle of a liquid thermometer,</i> - <i>use the scientific method (hypothesis - experiment - conclusion),</i> - <i>use correct scientific (physical) terminology.</i>

Module 3: Climate Science Experiments

Dissemination	<i>The results can be presented:</i> - on the bulletin board in the science/physics classroom - on the school website, - in the school magazine, - during the Open Day.
Next Steps	<i>The activity can be followed up by:</i> - comparing the expansion of water and alcohol, - constructing a simple liquid thermometer, - investigating the thermal expansion of solids, - investigating the effect of temperature on the electrical properties of substances (understanding the principle of a digital thermometer), - measuring the temperature of various surfaces, constructing a temperature map of the city.
Teacher Reflection	
<i>After the lesson, the teacher evaluates:</i> - Were the objectives achieved? - Which parts of the experiment were the most challenging for the students? - Was it necessary to adjust the organization of the work? - What questions did the students ask?	



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Module 3: Climate Science Experiments

- *What would be appropriate to change in the next implementation?*

Module 3: Climate Science Experiments

Activity 2 – Albedo: Investigating How Different Surfaces Reflect (and Absorb) Solar Radiation

Subject or subjects	<i>Science</i> <i>Physics</i> <i>Environmental education</i> <i>Geography</i> <i>Biology</i> <i>Mathematics (data processing and graph construction)</i>
Age/Level	<i>12–16 years, lower secondary education</i>
Time required	<i>60 – 90 minutes, or two lessons (45 min + 45 min)</i>
Learning goals	<i>Students are able to collaboratively plan an investigation comparing the ability of different surfaces to reflect solar radiation.</i> <i>Students are able experimentally investigate the influence of colour and surface type on surface heating.</i> <i>Students are able record experimental data.</i> <i>Students are able to interpret temperature measurements.</i> <i>Students are able to explain the concept of albedo as a measure of a surface's ability to reflect solar radiation.</i>

Module 3: Climate Science Experiments

	<i>Students are able to interpret experimental findings in the context of climate change and human settlements; propose measures to reduce urban overheating.</i>
Prior knowledge & skills	<i>Students:</i> - <i>understand the concept of temperature,</i> - <i>are able to use an infrared or digital thermometer,</i> - <i>can create simple tables and graphs,</i> - <i>understand the difference between the absorption and reflection of light.</i>
Materials, resources & settings	<i>For each group:</i> - <i>a piece of black cardboard,</i> - <i>a piece of white (light-coloured) cardboard,</i> - <i>a piece of aluminium foil,</i> - <i>one dark-coloured and one light-coloured tile (or two different types of roofing material),</i> - <i>an infrared thermometer,</i> - <i>a stopwatch,</i> - <i>for older students with more experience in experimental work, a smartphone with a light intensity measurement app,</i> - <i>direct sunlight (when using a powerful lamp, it is difficult to ensure identical conditions for all tested surfaces),</i> - <i>a student worksheet.</i>

Module 3: Climate Science Experiments

Classroom / science laboratory / school courtyard. (Ideally, the experiment should be carried out indoors in an area exposed to direct sunlight. In the school courtyard, the results may be affected by wind.)

Activity description

1. Motivation and introduction of the problem:

Use an image of a sunlit square with dark and light benches, the dark ones are empty, people are sitting on the light benches, photos of houses in Nordic countries (intense wall colour, dark roof) and in southern countries (light colours), or a photo of two people – one in a white and one in a black T-shirt.

Task: Describe what you see. What type of clothing do you prefer to wear during sunny summer weather?

Research question: How do the colour and type of a surface affect its heating when exposed to incoming solar radiation?

2. Experiment:

More experienced students may design the experimental procedure and data recording table independently, whereas less experienced students may use the following procedure and the table provided in the worksheet.

- Measure the initial temperature of the surfaces using an infrared thermometer.*
- Expose the surfaces to direct sunlight for 10 minutes.*
- Record the temperature of each surface every two minutes and perform at least five measurement series.*
- Construct a graph showing the relationship between temperature and time (plot the data for all investigated surfaces in the same coordinate system using different colours).*
- Compare the rates at which the different surfaces warm up.*

Module 3: Climate Science Experiments

If your school supports the BYOD (Bring Your Own Device) approach, the experiment can be extended by measuring the intensity of incoming and reflected light using a smartphone luxmeter application that uses the device's light sensor. Students can then experimentally demonstrate not only those different surfaces warm at different rates, but also that they differ in the amount of light they reflect. This extended investigation enables students to establish connections between the concepts of reflectivity, albedo, and surface temperature.

Students may wish to compare the effects of several colours rather than only black and white surfaces. In such cases, it is important to guide students to consider the influence of other parameters, such as surface finish (matte or glossy), material thickness, thermal conductivity, and the influence of the substrate. To investigate the effect of colour alone, students could use, for example, pieces of paper of identical size, thickness, and surface finish that differ only in colour.

3. Discussion

What caused the different surfaces to warm up?

Which surface warmed up the fastest? How would you explain this?

Which surface warmed up the slowest?

The discussion of the final question can lead to the introduction of the concept of albedo, for example: Albedo is a property of a surface that describes the fraction of incoming solar radiation reflected back into the surroundings. Surfaces with high albedo reflect a large proportion of the incoming radiation and therefore warm less. Surfaces with low albedo reflect only a small fraction of the incoming radiation, absorb most of it, and consequently warm more strongly.

4. Application and Explicit Connection to Climate Change

Why does the melting of snow and ice accelerate global warming?

How can green roofs or light-coloured roofs reduce urban overheating?

Module 3: Climate Science Experiments

Propose measures that could help your school respond to the challenges associated with climate change and overheating.

Accessibility & Inclusion

The activity supports the participation and collaboration of all students.

Inclusion can be further promoted through:

- *assigning specific roles within groups (e.g., experimenter, recorder, spokesperson, data analyst),*
- *adapting worksheets to students' needs (e.g., adding pictures or diagrams to accompany written descriptions of the experimental procedure, increasing font size, or providing additional space for written responses),*
- *allowing students to present their findings in alternative formats, such as a video presentation or a podcast, instead of a written laboratory report, while maintaining the same requirements regarding scientific content (i.e., description of the experiment and interpretation of the results).*

References Bibliography

Harlen, W. (2015). *Working with Big Ideas of Science Education*. Science Education Programme of IAP.

UCAR (2021) *Looking into Surface Albedo* UCAR Center for Science Education.
<https://scied.ucar.edu/activity/looking-surface-albedo>

Module 3: Climate Science Experiments

	ESA (2021) <i>Albedo Climate Game</i>. ESA Climate Office. https://climate.esa.int/media/documents/Albedo_Game.pdf
Assessment	
Formative Assessment	<i>During the activity, the teacher observes:</i> - the formulation of hypotheses, - the appropriateness of the experimental procedure, , - safe working practices, - collaboration within groups, - students' ability to interpret results, - the correct use of concepts such as reflection, absorption, and albedo. <i>The teacher may use guiding questions such as:</i> - What did you measure? - Was your hypothesis confirmed? - How do you explain the differences in the heating of the various surfaces?
Summative Assessment (if applicable)	<i>Assessment may focus on:</i> - the completeness and accuracy of the completed worksheet, - the correctness of the graphical representation of the experimental data, - the conclusions – the interpretation of the experimental results, - the explanation of the concept of albedo,

Module 3: Climate Science Experiments

	- the proposed measures to reduce overheating at the school, including the use of albedo-related principles and the feasibility of the proposed solutions.
Student Self-Assessment	At the end of the lesson, students complete statements such as: - Today I learned that... - What surprised me most was... - Next time, I would like to... Alternatively, students may indicate their level of understanding using a self-assessment scale: ☐ I understand completely. ☐ I understand with a little help. ☐ I need further explanation.
Peer Feedback	Each group briefly presents its findings. Other students may provide feedback by considering questions such as: • What was particularly clear in the presentation? • What did you find interesting? • What question would you ask this group?
Documentation, Evidence & Follow-Up	
Evidence to Collect	- Completed worksheets, - students' hypotheses, - measurement tables, - graphical representations of experimental data, - photographs documenting the experiment,



Module 3: Climate Science Experiments

	- <i>students' proposals for school.</i>
Impact Tracking	<i>The teacher observes whether students are able to:</i> - <i>explain the concept of albedo,</i> - <i>interpret measurement results,</i> - <i>connect physical concepts with climate change phenomena,</i> - <i>propose evidence-based solutions.</i>
Dissemination	<i>Results may be presented:</i> - <i>on a notice board in the science or physics classroom,</i> - <i>on the school's website,</i> - <i>in the school magazine,</i> - <i>during Earth Day activities or thematic project days.</i>
Next Steps	<i>The activity can be followed by:</i> - <i>measuring the temperature of different surfaces around the school (e.g. asphalt, short and tall grass, paving stones, and soil),</i> - <i>measuring the temperature under a tree and in direct sunlight (to demonstrate the cooling effect of water evaporation from leaves—briefly immerse the sensor of a digital thermometer in water and observe the temperature as the water evaporates from the sensor),</i> - <i>creating a map of urban heat islands around the school or a temperature map of the local area,</i> - <i>the Albedo Climate Game activity.</i>



Module 3: Climate Science Experiments

Teacher Reflection	
<i>After the lesson, the teacher reflects on the following questions:</i> - <i>Were the learning objectives achieved?</i> - <i>Which parts of the experiment were most challenging for students?</i> - <i>Was it necessary to modify the organization of the activity?</i> - <i>What questions did students ask?</i> - <i>Were students able to distinguish between the concepts of albedo, reflectivity, and surface temperature?</i> - <i>What could be improved in future implementations of the activity?</i>	

After the lesson, the teacher reflects on the following questions:

- *Were the learning objectives achieved?*
- *Which parts of the experiment were most challenging for students?*
- *Was it necessary to modify the organization of the activity?*
- *What questions did students ask?*
- *Were students able to distinguish between the concepts of albedo, reflectivity, and surface temperature?*
- *What could be improved in future implementations of the activity?*



Module 3: Climate Science Experiments

Activity 3 - The Greenhouse Effect: Investigating How the Atmosphere Influences the Earth's Temperature

Subject or subjects	<i>Science</i> <i>Physics</i> <i>Geography</i> <i>Biology</i> <i>Environmental Education</i> <i>Chemistry (composition of the atmosphere), Mathematics (data processing and graph construction)</i>
Age/Level	<i>12–16 years, lower secondary education</i>
Time required	<i>Complete activity, including information gathering about the greenhouse effect and greenhouse gases, as well as the experiment: 60–90 minutes, or two lessons (45 min + 45 min).</i> <i>Experiment and data analysis only: 45 minutes.</i>
Learning goals	<i>The student is able to search for information and evaluate it critically.</i> <i>The student is able to collaboratively plan an experiment comparing temperature changes in a closed and an open environment.</i> <i>The student is able to record experimental data.</i>



Module 3: Climate Science Experiments

	<i>The student is able to interpret the measurement results and critically evaluate how the classroom experiment is similar to and different from the greenhouse effect in the atmosphere.</i> <i>The student:</i> - <i>distinguishes between the natural and the enhanced greenhouse effect,</i> - <i>explains the role of the atmosphere in maintaining the Earth's temperature, its importance for life on Earth, and its connection to climate change.</i>
Prior knowledge & skills	<i>The student:</i> - <i>understands the concept of temperature,</i> - <i>can use a digital thermometer,</i> - <i>can use a CO₂ sensor, if available,</i> - <i>can construct a simple table and graph,</i> - <i>understands the difference between the reflection, absorption, and emission of energy.</i>
Materials, resources & settings	<i>For each group:</i> - <i>two identical transparent containers (e.g. glass jars or plastic containers),</i> - <i>two identical dark-coloured bases (e.g. black cardboard or black fabric), each at least as large as the base of the transparent container,</i> - <i>two digital or liquid-in-glass thermometers that can be placed inside the transparent containers,</i>

Module 3: Climate Science Experiments

- transparent plastic wrap,
- 100 ml of vinegar,
- one tablespoon of baking soda,
- a stopwatch,
- optionally, a CO₂ sensor,
- direct sunlight or a lamp,
- a student worksheet.

Classroom / science laboratory.

Activity description

1. Motivation and introduction to the problem:

Imagine that you are a team of young scientists who have been asked by a meteorological station to help investigate an important question. Over the past decades, the Earth's average temperature has been increasing, and scientists are trying to understand why this is happening. Your task is to investigate how the greenhouse effect works, explain why it is essential for life on Earth, and determine when this natural phenomenon becomes a problem.

During the investigation, you will work with scientific information, carry out a simple experiment, analyze the results, and finally prepare recommendations on how each of us can help reduce the enhanced greenhouse effect.

2. Experiment:

More experienced students may plan the experimental procedure and design their own data-recording table. Less experienced students may use the procedure and table provided in the student worksheet.

- *Pour equal amounts of vinegar (approximately 50 ml) into both containers and add one tablespoon of baking soda to one of them. Place a thermometer in each*

Module 3: Climate Science Experiments

container and seal both containers with transparent plastic wrap. In the container containing baking soda, carbon dioxide is produced through its reaction with vinegar.

- Place both containers on a dark surface and expose them to direct sunlight (or illuminate them with a lamp).
- Record the temperature in each container every two minutes for 15–20 minutes and enter the measurements into the table.
- Plot a graph of temperature versus time, displaying the data from both containers on the same set of axes using different colours.
- Compare the rate at which the contents of the two containers warm up.

3. Discussion:

In what ways is the experiment similar to the greenhouse effect in the atmosphere, and in what ways is it different?

In the covered containers, the higher temperature is mainly caused by the transparent plastic wrap reducing air movement (convection). As a result, warm air cannot easily escape upward from the container. The term greenhouse effect originates from this mechanism, as a greenhouse is warmed primarily because the glass limits air circulation.

In the atmosphere, however, the greenhouse effect operates through a different mechanism. Solar radiation passes through the atmosphere and warms the Earth's surface. The warmed surface then emits infrared radiation. Greenhouse gases (water vapour, CO₂, CH₄, and others) absorb part of this infrared radiation and re-emit it in all directions. Part of the absorbed radiation is emitted back towards the Earth's surface, increasing its temperature. In the experiment, one container contained a higher concentration of carbon dioxide, which absorbed a greater proportion of the infrared radiation emitted by the dark surface beneath it. As a result, the container with carbon dioxide reached a higher temperature.

4. The greenhouse effect – friend or threat?



Module 3: Climate Science Experiments

Each group prepares a short presentation, poster, story, or comic strip addressing the following questions:

- *How does the greenhouse effect work?*
- *Why is the natural greenhouse effect important?*
- *Why do we now talk about the enhanced greenhouse effect?*
- *What can we do to reduce greenhouse gas emissions?*

This task develops scientific literacy, critical thinking, data analysis, and argumentation skills while naturally integrating physics, geography, chemistry, and environmental education.

The natural greenhouse effect is essential for life on Earth. Without it, most of the heat emitted by the warmed Earth's surface would escape into space, and the Earth's average temperature would be approximately -18°C . Because greenhouse gases in the atmosphere (primarily water vapour, carbon dioxide, methane, and nitrous oxide) retain part of this heat, the Earth's average temperature is approximately $+15^{\circ}\text{C}$.

The problem is the enhanced greenhouse effect, which results from increasing concentrations of greenhouse gases caused by human activities. This causes more heat to be retained in the atmosphere than under natural conditions, leading to global warming and climate change.

Accessibility & Inclusion

The activity promotes the participation and collaboration of all students.

Inclusion can be further supported by:

- *assigning roles within each group (e.g. measurer, recorder, data analyst, and presenter),*

Module 3: Climate Science Experiments

	- adapting the student worksheets (e.g. adding illustrations to accompany the written description of the experimental procedure, increasing the font size, or providing more space for written responses), - allowing students to choose the format of the final assessment task (e.g. a presentation, poster, audio recording, story, or comic strip), - using digital sensors with automatic data recording, - providing teacher support when interpreting graphs.
References / Bibliography	Harlen, W. (2015). <i>Working with Big Ideas of Science Education</i>. Science Education Programme of IAP. ESA (2022) <i>The greenhouse effect and its consequences - Investigating global warming</i>. ESA Education Office. https://www.esa.int/Education/Teachers_Corner/The_greenhouse_effect_and_its_consequences_-_Investigating_global_warming_Teach_with_space_G03?utm_source=chatgpt.com ESA (2022) <i>Investigating Greenhouse gases. Mini Case Study For Climate Detectives</i> ESA Education Office. Investigating_Greenhouse_Gases_Mini_Case_Study_for_Climate_Detectives.pdf
Assessment	
Formative Assessment	During the activity, the teacher observes: - formulation of hypotheses, - the correctness of the experimental procedure,

Module 3: Climate Science Experiments

	- safe working practices, - collaboration within the group, - students' ability to interpret the results, - students' ability to distinguish between the model and the real phenomenon, - the correct use of the terms infrared radiation, atmosphere, greenhouse effect, and greenhouse gases. The teacher uses guiding questions such as: - What did you measure? - Was your hypothesis confirmed? - How do you explain the difference in the warming of the two containers?
Summative Assessment (if applicable)	The following can be assessed: - the completeness and accuracy of the completed student worksheet, - the correctness of the graphical representation of the experimental data, - the conclusion and interpretation of the experimental results, - the comparison of the natural and enhanced greenhouse effects and students' ability to critically evaluate the experimental model.
Student Assessment	Self- At the end of the lesson, students complete one of the following:

Module 3: Climate Science Experiments

	- <i>Today I understood that...</i> - <i>What surprised me most was...</i> - <i>Next time I would like to...</i> or indicate their self-assessment using the following scale: ☐ <i>I understand completely.</i> ☐ <i>I understand with a little help.</i> ☐ <i>I need further explanation.</i>
Peer Feedback	Each group briefly presents its results. The other students may evaluate: - <i>the clarity of the explanation,</i> - <i>the correctness of the interpretation,</i> - <i>the use of arguments supported by the measured data.</i>
Documentation, Evidence & Follow-Up	
Evidence to Collect	- <i>student worksheets,</i> - <i>students' hypotheses,</i> - <i>measurement tables,</i> - <i>graphical representations of the experimental data,</i> - <i>photographs documenting the experiment,</i> - <i>final group outputs.</i>
Impact Tracking	The teacher observes whether students: - <i>understand the mechanism of the natural greenhouse effect,</i>

Module 3: Climate Science Experiments

	- distinguish between the model and the actual physical process, - are able to explain the role of greenhouse gases, - use scientific arguments when discussing climate change.
Dissemination	The results may be presented: - on a noticeboard in the science or physics classroom, - on the school's website, - in the school magazine, - during Earth Day or a thematic project day.
Next Steps	The activity can be followed by: - investigating the effect of different CO₂ concentrations, - conducting an experiment on the absorption of infrared radiation by different materials, - searching for information about the Earth's energy balance, - discussing ways to reduce human greenhouse gas emissions.
Teacher reflection	
After the lesson, the teacher reflects on the following questions: - Were the learning objectives achieved? - Which parts of the experiment were the most challenging for the students? - Was it necessary to modify the organization of the activity?	



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- *What questions did the students ask?*
- *Did the students understand the difference between a greenhouse and the greenhouse effect?*
- *Were the students able to relate the experiment to the Earth's energy balance?*
- *Which concepts did the students find most difficult?*

Module 3: Climate Science Experiments

Activity 4 - Water Acidification: Investigating How Carbon Dioxide Dissolves in Water and Its Effects on the Calcium Carbonate Shells of Marine Organisms

Subject or subjects	Science Chemistry Biology Physics Environmental Education Mathematics and Computer Science (data processing and visualization)
Age/Level	12–16 years, lower secondary education
Time required	45 minutes + 15 minutes in the following lesson (with an interval of at least 24 hours)
Learning goals	The student is able to search for information and evaluate it critically. The student is able to collaboratively plan an experiment comparing the effect of water temperature on the solubility of carbon dioxide. The student is able to record experimental data. The student is able to interpret the experimental results. The student is able to:

Module 3: Climate Science Experiments

	- experimentally demonstrate and explain that carbon dioxide dissolves in water, - experimentally verify that the solubility of CO₂ depends on water temperature, - explain the concept of water acidification and describe its causes and consequences, - explain that two opposing factors influence the dissolution of carbon dioxide: increasing atmospheric carbon dioxide concentration and increasing temperature.
Prior knowledge & skills	The student: - understands the concepts of temperature, pH, acids, and alkali (at an age-appropriate level), - can use a digital thermometer, - can determine the approximate pH of a solution using indicator paper, - can construct a simple table.
Materials, resources & settings	For each group: - two identical transparent containers (e.g. glass jars), - cold water (approximately 10 °C) and warm water (approximately 40 °C), - two drinking straws, - a digital thermometer, - four pH indicator strips or a pH sensor, - a stopwatch, - a student worksheet,

Module 3: Climate Science Experiments

- a mobile phone or camera for documenting the colour change of the pH indicator strips,
- two digital or liquid-in-glass thermometers that can be placed inside the transparent containers,
- transparent plastic wrap,
- 100 ml of vinegar,
- one tablespoon of baking soda,
- a stopwatch,
- optionally, a CO₂ sensor,
- direct sunlight or a lamp,
- a student worksheet,
- a glass,
- vinegar,
- a chicken egg, a snail shell, or another calcium carbonate shell.

Classroom / chemistry laboratory / science laboratory.

Activity description

1. Motivation and introduction to the problem:

The teacher brings two bottles of the same brand of carbonated mineral water, one chilled and the other at room temperature (or warmed in direct sunlight). Both bottles are opened.

Students observe that considerably more bubbles escape from the warm mineral water.

The teacher moderates a discussion without immediately explaining the phenomenon, instead using students' ideas to formulate research questions, for example:

- Which bottle of mineral water fizzed more—the warm one or the cold one?

Module 3: Climate Science Experiments

- *What are the bubbles in carbonated mineral water made of?*
- *Why were there more bubbles in the warm water? (The two bottles contained the same type of mineral water and therefore the same total amount of carbon dioxide.)*
- *Think about the amount of carbon dioxide that remained dissolved in the mineral water. Was it the same in the warm and the cold bottle?*

2. Experiment:

Students formulate a hypothesis, for example: More carbon dioxide dissolves in cold water than in warm water.

Students work in groups of three or four. More experienced students may design the experimental procedure and the data table independently. Less experienced students may follow the procedure and use the table provided in the student worksheet.

1. *Pour equal amounts of water into two containers. Fill one with warm water and the other with cold water.*
2. *Use a pH indicator to determine the approximate pH of the water in both containers. (Take photographs of the indicator strips.)*
3. *Gently blow air through drinking straws into both containers for two minutes.*
4. *Use the pH indicator again to determine the approximate final pH of the water in both containers. (Take photographs of the indicator strips.)*
5. *Record the results in the table.*

3. Discussion:

In which container did the pH change more—in the warm water or the cold water? How do you explain this?

What is the relationship between temperature and the solubility of CO₂?

What happens to carbon dioxide after it dissolves in water? Carbon dioxide reacts with water to form carbonic acid, which partially dissociates, producing hydrogen ions. As a result, the pH decreases.

4. Information search:

Module 3: Climate Science Experiments

Students may search for information individually or in groups, either online during the lesson or as homework before the next lesson. The teacher may guide their work using questions such as:

- *Find information about changes in the concentration of carbon dioxide in the atmosphere.*
- *How do human activities contribute to these changes?*
- *What proportion of atmospheric carbon dioxide is absorbed by oceans?*
- *Find information about the effects of increasing ocean temperature and rising atmospheric carbon dioxide concentrations on ocean acidification.*

5. *The effect of water acidification on the calcium carbonate shells of marine organisms – demonstration:*

Place a chicken egg (or another calcium carbonate shell) in a glass and cover it with vinegar, which is an aqueous solution of acetic acid.

Observe the effect of the acid on the shell together with the students during the following lesson (after at least 24 hours).

When discussing the observations, it is important to explain that vinegar contains a much higher concentration of hydrogen ions than seawater. Therefore, this demonstration represents only a model of the effect of ocean acidification on the calcium carbonate shells of marine organisms.

Accessibility & Inclusion

The activity promotes the participation and collaboration of all students.

Inclusion can be further supported by:

- *forming heterogeneous groups and assigning roles within each group (e.g. timekeeper, student blowing air through the straw, recorder, and data analyst),*
- *adapting the student worksheets (e.g. adding illustrations to accompany the written description of*

Module 3: Climate Science Experiments

	<i>the experimental procedure, increasing the font size, providing more space for written responses, or including a diagram of the chemical processes),</i> - <i>allowing gifted students to search for information independently, guiding mainstream students through targeted questions, and providing students with special educational needs with prepared information materials.</i>
References Bibliography	Harlen, W. (2015). <i>Working with Big Ideas of Science Education</i>. Science Education Programme of IAP. NOAA (n.d.) <i>Education and Outreach</i>. National Ocean and Atmospheric Administration - Ocean Acidification Program. https://oceanacidification.noaa.gov/ocean-acidification-education-outreach/ UNESCO (2021). <i>Ocean Acidification</i>. United Nations Decade of Ocean Science for Sustainable Development (2021-2030). https://drive.google.com/file/d/1noc9E-oULdpBKTmbaoyN6LevjNee48DC/view
Assessment	
Formative Assessment	<i>During the activity, the teacher observes:</i> - <i>safe working practices,</i> - <i>collaboration within the group,</i> - <i>students' reasoning when interpreting the results and their use of scientific terminology.</i>

Module 3: Climate Science Experiments

	<i>The teacher uses guiding questions such as:</i> - <i>What did you find?</i> - <i>Were your predictions confirmed?</i> - <i>How do you explain the difference in the solubility of carbon dioxide in warm and cold water?</i>
Summative Assessment (if applicable)	<i>The following can be assessed:</i> - <i>the completeness and accuracy of the completed student worksheet,</i> - <i>the conclusion and interpretation of the experimental results.</i>
Student Self-Assessment	<i>At the end of the activity, students complete a short self-assessment form, for example:</i> <i>Today I can explain:</i> ☐ <i>why the pH of the oceans decreases,</i> ☐ <i>what affects the dissolution of carbon dioxide in water,</i> ☐ <i>why coral reefs are under threat.</i>
Peer Feedback	<i>Each group briefly presents its results. The other students may evaluate:</i> - <i>the clarity of the explanation,</i> - <i>the correctness of the interpretation,</i> - <i>the use of arguments supported by the measured data.</i>



Module 3: Climate Science Experiments

Documentation, Evidence & Follow-Up	
Evidence to Collect	- <i>student worksheets,</i> - <i>students' hypotheses,</i> - <i>measurement tables,</i> - <i>photographs documenting the experiment,</i> - <i>final group outputs.</i>
Impact Tracking	<i>The teacher observes whether students:</i> - <i>correctly use scientific terminology (e.g. pH, acidification, solubility, and, where appropriate, partial pressure),</i> - <i>relate the experiment to real-world phenomena,</i> - <i>formulate evidence-based arguments,</i> - <i>distinguish between the model and the actual physical process.</i>
Dissemination	<i>The results may be presented:</i> - <i>on a noticeboard in the science or physics classroom,</i> - <i>on the school's website,</i> - <i>in the school magazine,</i> - <i>during Earth Day or a thematic project day.</i>
Next Steps	<i>The activity can be followed by:</i> 1. <i>analyzing ocean pH data from the Copernicus database,</i> 2. <i>discussing ways to reduce carbon dioxide emissions.</i>



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Module 3: Climate Science Experiments

Teacher Reflection

After the lesson, the teacher reflects on the following questions:

- 1. Were the students able to explain the causal relationship between CO₂ emissions and ocean acidification?*
- 2. Was the experiment appropriately challenging and safe?*
- 3. Did all students have the opportunity to participate actively?*
- 4. Which parts of the activity generated the greatest interest or the most questions?*
- 5. How could the activity be adapted or extended for future implementation?*

Module 3: Climate Science Experiments

Activity 5 - Temperature Map of the School Surroundings / Town

Subject or subjects	<i>Physics</i> <i>Geography</i> <i>Environmental Education</i> <i>Cross-curricular links: Computer Science (data processing and visualization), Mathematics (statistics and graphs)</i>
Age/Level	<i>12 – 16 years (ISCED 2)</i>
Time required	<i>The activity can be carried out either as one larger project or as a series of independent inquiry-based tasks.</i> Lesson 1 (45 min): Factors affecting surface temperature and planning the measurements. Lesson 2 (45–60 min): Field measurements. Lesson 3 (45 min): Data analysis, creation of a temperature map, and interpretation of the results. Lesson 4 (45 min): Developing recommendations and presenting the results.
Learning goals	<i>Students understand that their decisions and actions can influence climate change and its impacts on quality of life.</i> <i>Students are able to explain the difference between air temperature and the temperature of an object's surface and understand how air is heated by the Earth's surface.</i>



Module 3: Climate Science Experiments

	<i>Students are able to identify the factors affecting surface temperature (colour, material, albedo, vegetation, shade, and wind) and describe their effects.</i> <i>Students are able to use experimentally collected data to propose practical measures for reducing overheating in the school grounds or the surrounding area.</i> <i>Students are able to:</i> - <i>safely use a contact or infrared thermometer,</i> - <i>collaborate with others to plan an experiment and identify the variables to be measured,</i> - <i>record and analyse experimental data,</i> - <i>create a simple temperature map of the school surroundings,</i> - <i>interpret the results using scientific arguments.</i>
Prior knowledge & skills	<i>The student:</i> - <i>understands the concept of temperature,</i> - <i>can use a digital or infrared thermometer,</i> - <i>understands the concepts of albedo and thermal radiation (or the teacher briefly reviews them),</i> - <i>can work collaboratively and record data in a table.</i>
Materials, resources & settings	<i>For each group:</i> - <i>an infrared thermometer or a digital thermometer for measuring air temperature,</i>

Module 3: Climate Science Experiments

	- a map of the school grounds or the surrounding area, - a student worksheet, - a pencil, - optional: a measuring tape or ruler (to identify measurement locations), a mobile phone or tablet (for photographs and GPS location), and/or a light meter application (lux meter). School grounds or the surrounding area (e.g. a park, town square, or residential neighbourhood).
Community/Stakeholder Involvement (optional)	Possible partners include: - the local municipal authority, - staff from the environmental department, - organizations working on urban climate change adaptation.
Activity description	
Depending on the students' prior experience and the intended learning objectives, the activity may take the form of an open challenge, a student-designed investigation, or a teacher-designed inquiry activity. The following describes a series of inquiry-based tasks planned by the teacher: 1. What affects surface temperature? Using brainstorming, students compile a list of potential factors that influence the surface temperature of different materials and objects. Each group experimentally investigates the effect of one selected factor.	

Module 3: Climate Science Experiments

Expected factors include: ambient temperature (air and ground temperature), direct sunlight, altitude, orientation towards the cardinal directions, wind, the degree of enclosure of the area (e.g. the microclimate of a courtyard), object colour, the heat capacity of the material, and its thermal conductivity.

Planning the measurements:

Students decide whether they will measure the surface temperature of objects or the air temperature (and, if measuring air temperature, at what distance from the nearest object). They determine where the measurements will be taken (e.g. asphalt, concrete, a sandbox, short grass, tall grass, tree bark, metal railings, a building façade, or a water surface), when the measurements will be taken (considering the time of day, current weather conditions, and synchronization), whether they will measure at a single point in time or monitor changes throughout the day, and how they will ensure that the measurements are comparable.

Students discuss questions such as:

Is it better for each group to measure all locations one after another, or for each group to measure a different location at the same time? Is it useful to measure both in the shade and in direct sunlight? How are the results affected by wind? How are the results affected by vegetation?

More experienced students do not need to use the prepared worksheet during the field investigation. In that case, however, they should design their own method for recording the experimental data. It is recommended that they record the characteristics of each measurement site (location, surface type, whether it was in direct sunlight or shade), the exact time of measurement, the measured temperature, and, if possible, a photograph of the location.

2. Field measurements

The teacher prepares a map of the area in which students may carry out the investigation (e.g. the school grounds, a town square with a park, or, for older students, the wider surroundings of the school or different parts of the town).



Module 3: Climate Science Experiments

Students work in groups of two or three and assign roles to each group member. Each group collects the necessary equipment (thermometer, pencil, worksheet, and, where appropriate, a measuring tape, mobile phone, or tablet) and carries out the field measurements.

3. Data analysis and creation of a temperature

a) Students share their measurement results by creating a combined data table on the board or in a shared online document.

If different groups obtain different results for the same measurement locations, possible reasons for these differences should be discussed.

b) Each group decides (or is assigned by the teacher) how the experimental data will be processed. They may create tables, graphs, colour-coded maps, or isotherm maps.

Students may use tools such as Google My Maps, Google Sheets, or Microsoft Excel for data processing.

c) Data interpretation (evaluating the results in relation to the expectations developed during Activity 1, What affects surface temperature?).

Students may discuss questions such as:

- Which location was the warmest?*
 - Which location was the coolest?*
 - Why?*
 - What role did vegetation play?*
 - What effect did surface colour have?*
 - The term urban heat island is used to describe the persistently higher temperatures observed in cities and densely built-up areas compared with the surrounding natural landscape. How would you explain this phenomenon?*
- What causes urban heat islands?*

(The main causes include anthropogenic heat released from transport, buildings, and industry; the low reflectivity (albedo) of dark urban surfaces,

Module 3: Climate Science Experiments

which absorb a large proportion of incoming shortwave solar radiation and release the stored energy as longwave thermal radiation; the relatively high heat capacity of concrete and asphalt, which release the heat accumulated during the day throughout the night; and the limited amount of vegetation, which cools the environment through the evaporation of water.)

4. Proposing local solutions and presenting the results

Students form new groups of four or five so that each new group includes students who participated in different groups during the previous activities.

Depending on the learning objectives, students may be asked to:

- a) propose at least three measures to reduce the urban heat island effect and present their proposals to the class;*
- b) design and plan one specific measure to reduce the urban heat island effect and present the proposal to relevant stakeholders (e.g. the school management, the local council, or a homeowners' association).*

If any of the proposed measures are implemented, Activities 2 (Field measurements) and 3 (Data analysis and creation of a temperature map) can be repeated after some time to evaluate the impact of the implemented changes.

Accessibility & Inclusion

The activity promotes the participation of all students.

- Inclusion can be supported, for example, by:*
- assigning specific roles within each group (e.g. measurer, recorder, photographer, or presenter),*
- adapting the student worksheets (e.g. by adding illustrations, checklists of tasks, providing more space for written responses, or supplying an electronic version of the worksheet),*

Module 3: Climate Science Experiments

	- allowing students to create a podcast instead of submitting written proposals and justifications in Activity 4, Proposing Local Solutions.
References / Bibliography	Harlen, W. (2015). <i>Working with Big Ideas of Science Education</i>. Science Education Programme of IAP. Teaching Green (n.d.) <i>How diverse surfaces and materials create heat islands</i>. Teaching Greens Initiative. https://www.teachinggreen.eu/wp-content/uploads/modules/Hot_temperature_Janovce_Slovakia/res/index.html ESA (2020). <i>Urban Hotspots</i>. ESA Climate Change Initiative. https://climate.esa.int/media/documents/ESA_CCI_Education_Resources_Urban_Hotspots.pdf NASA (2010, Dec. 14). <i>Urban Heat Islands</i>. NASA Earth Observatory. https://science.nasa.gov/earth/earth-observatory/urban-heat-islands-47704/
Assessment	
Formative Assessment	<i>The teacher continuously observes:</i> - the planning of the investigation, - the formulation of hypotheses, - the accuracy of the measurements, - collaboration within the group, - the interpretation of the data, - the use of scientific arguments.

Module 3: Climate Science Experiments

Summative Assessment (if applicable)	<i>The following may be assessed:</i> - the temperature map, - the group presentation, - the proposed adaptation measures, - the quality of the interpretation of the results. <i>It is recommended to use an assessment rubric aligned with the specific learning objectives and the format of the individual activities.</i>
Student Self-Assessment	<i>At the end of each activity (lesson), students complete the following:</i> 1. Today I understood that... 2. What surprised me most was... 3. Next time I would like to... 4. I contributed most to my group's work by... <i>or indicate their self-assessment using the following scale:</i> ☐ I understand completely. ☐ I understand with a little help. ☐ I need further explanation.
Peer Feedback	<i>After each group presentation, the other students provide feedback by completing the following statements:</i> 1. I liked... 2. I would like to know... 3. I would recommend...



Module 3: Climate Science Experiments

Documentation, Evidence & Follow-Up	
Evidence to Collect	1. <i>student worksheets,</i> 2. <i>photographs documenting the measurements,</i> 3. <i>tables of the recorded measurements,</i> 4. <i>graphs,</i> 5. <i>temperature maps,</i> 6. <i>presentations of the results,</i> 7. <i>presentations of the proposed measures.</i>
Impact Tracking	<i>Throughout the series of activities, the teacher may monitor:</i> 1. <i>students' understanding of the factors affecting the microclimate,</i> 2. <i>their ability to plan an experiment,</i> 3. <i>the quality of the recorded data,</i> 4. <i>the quality of the data interpretation,</i> 5. <i>their ability to propose evidence-based solutions,</i> 6. <i>the development of environmental responsibility.</i>
Dissemination	<i>The outcomes (proposed measures to mitigate the urban heat island effect) may be presented to:</i> - <i>the school management,</i> - <i>the student council,</i> - <i>parents,</i> - <i>the local municipal council.</i>
Next Steps	<i>Possible extensions of the project include:</i>



Module 3: Climate Science Experiments

- | | |
|--|---|
| | <ol style="list-style-type: none">1. <i>demonstrating the effect of vegetation (evaporation) on temperature,</i>2. <i>repeating the measurements in different seasons,</i>3. <i>comparing morning and afternoon temperatures,</i>4. <i>monitoring the effectiveness of the proposed measures,</i>5. <i>creating a long-term database of measurements.</i> |
|--|---|

Teacher Reflection

Were the learning objectives achieved?

Were the students able to design the investigation independently?

Which factors surprised the students the most?

Was the organization of the field measurements effective?

Were the students able to relate the physical concepts to the real environment of the school?

Were the students' proposed measures supported by evidence? How could the quality and depth of their proposed solutions be further improved?

Module 3: Climate Science Experiments

Activity 6 - Glacier Melting

Subject or subjects

Physics
Geography
Environmental Education
Chemistry

Age/Level

12–16 years, lower secondary education

Time required

The activity can be carried out either as one larger project or as a series of independent inquiry-based tasks.

The duration depends on the number of inquiry tasks included and on whether students design their own experimental procedures or follow a teacher-designed protocol.

Lesson 1 (45 min): How does glacier melting affect sea level? Planning an experiment investigating the effects of glacier formation and melting on ocean salinity, and, if necessary, preparing a saline solution.

Lesson 2 (45 min): Experiment: How do glacier formation and melting affect ocean salinity? Data analysis and a demonstration of the effect of glacier melting on ocean currents.

Before the activity, sufficient time should be allowed for preparing the ice.

Module 3: Climate Science Experiments

Learning goals	<i>Before the activity, sufficient time should be allowed for preparing the ice.</i> <i>Students are able to:</i> - <i>respond to the opinions of others and use arguments based on scientific evidence during discussions,</i> - <i>collaboratively plan an experiment,</i> - <i>record experimental data,</i> - <i>interpret the results of the experiment.</i> <i>Students are able to apply Archimedes' principle to explain the effect of melting sea ice on sea level. They are also able to describe and explain the complex impacts of glacier melting on ecosystems.</i>
Prior knowledge & skills	<i>Students are expected to:</i> - <i>understand the solid, liquid, and gaseous states of matter,</i> - <i>have an intuitive understanding of the conservation of mass,</i> - <i>measure volume using a graduated cylinder,</i> - <i>measure mass using a digital scale,</i> - <i>measure temperature using a liquid-in-glass and/or digital thermometer,</i> - <i>where appropriate, calculate density as the ratio of mass to volume and/or measure the density of a liquid using a hydrometer (depending on the chosen format of the investigation into the effects of glacier formation and melting on ocean salinity).</i>

Module 3: Climate Science Experiments

Materials, resources & settings

Materials:

For preparing the ice: water or a saline solution, plastic cups, a freezer

For preparing the saline solution: water, salt, a digital scale, and a PET bottle

1. Effect of glacier melting on sea level:

- two transparent or translucent containers,
- ice cubes,
- tap water,
- a fine permanent marker or coloured adhesive tape for marking the initial water level,
- modelling clay, plasticine, soil, or gravel (to represent land),
- optionally, a graduated cylinder..

2. Effect of glacier formation and melting on ocean salinity:

- a saline solution (prepared from water, table salt, a digital scale, and a PET bottle),
- small plastic containers (e.g. yoghurt cups),
- a dropper or syringe,
- a waterproof surface (e.g. a plastic sheet),
- optionally, a graduated cylinder and a hydrometer.

3. Effect of glacier melting on ocean currents:

- two identical transparent containers (e.g. glass jars),
- old water (approximately 10 °C) and hot water (approximately 40 °C),
- a digital thermometer,
- cardboard or stiff paper,

Module 3: Climate Science Experiments

- a tray (to protect the surrounding area from spilled water),
- a sponge or paper towels (in case of spills),
- optionally, food colouring.

Resources: concept comic, student worksheets.

Learning environment: classroom / physics laboratory.

Activity description

1. How does glacier melting affect sea level?

The activity begins by eliciting students' existing conceptions. This can be done either:

- a) through a whole-class discussion centered on the question: What happens to sea level when glaciers melt?
- b) using a concept cartoon.

For students who are already familiar with **Archimedes' principle**, it is important to guide the discussion so that they use it to justify their predictions about the effect of melting floating sea ice on sea level.

If students expect sea level to rise even when floating sea ice melts, or if they are uncertain, the teacher asks them to design a model representing both floating sea ice and land ice. The models may then be demonstrated either by the teacher or through a whole-class experiment. For example:

a) Model of melting sea ice:

Fill a transparent container with water and place several ice cubes into it. Mark the initial water level with a fine permanent marker or coloured adhesive tape. Will the water level change after the ice has melted?

Module 3: Climate Science Experiments

The demonstration is most convincing if part of the floating ice initially protrudes above the water surface and the water level is close to the rim of the container. If the floating ice does not touch the rim of the container, the water will not overflow after all the ice has melted. Alternatively, a graduated cylinder may be used, as its scale makes changes in water level easier to observe.

b) Model of melting land ice:

Create a model of land inside a transparent container using gravel, modelling clay, or another suitable solid object. Place the same amount of ice used in part (a) on the model land. Mark the initial water level with a fine permanent marker or coloured adhesive tape. Will the water level change after the ice has melted?

Note: If students can choose from containers of different sizes, encourage them to consider how the surface area of the water and the amount of ice influence the visibility of the expected change in water level. You may ask questions such as: What volume of water will be produced when the ice melts? If this volume spreads over the entire surface of the container, how thick will the resulting layer of water be?

2. How do glacier formation and melting affect ocean salinity?

Students first discuss the central question: "Does the salinity of the ocean change when sea ice forms or melts?" They will probably predict that the melting of land ice decreases ocean salinity because fresh water flows into the sea. But what happens when sea ice melts or when it forms by freezing seawater? Is the ice formed from seawater itself salty?

Planning the experiment: Students work in groups of two or three to design an experiment investigating the effect of glacier formation and melting on ocean salinity. Less experienced students may follow the procedure provided in the student worksheet. It is appropriate to compare:

- 1. tap water,*
- 2. seawater (a saline solution),*
- 3. water obtained by melting the frozen part of the saline solution,*

Module 3: Climate Science Experiments

4. the unfrozen part of the saline solution.

Students may propose one of the following methods for comparing salinity:

- a) Comparing density calculated from the measured mass and volume of each liquid (depending on the accuracy of the measuring instruments, the differences in density may be comparable to the measurement uncertainty)
- b) Comparing density measured using a suitable hydrometer.
- c) Comparing the evaporation residues remaining after a small quantity of each liquid has evaporated. If only a single drop of each solution is placed on a plastic sheet during a warm, dry day, the drops may evaporate within approximately five minutes.
- d) Qualitatively comparing the taste (saltiness) of the solutions by placing one drop on the tongue. If this method is used, strict hygiene must be maintained, and a sterile dropper or sterile syringe should be used.

If students have access to natural seawater, they may use it in the experiment. Otherwise, an artificial seawater solution should be prepared. Students may search for information about the average salinity of a selected sea, or they may use the teacher-provided value of 3.5%, which corresponds approximately to the average salinity of the Mediterranean Sea. Using tap water, table salt, a digital scale, and a PET bottle, students can prepare the saline solution themselves. Alternatively, the teacher may prepare it for the entire class.

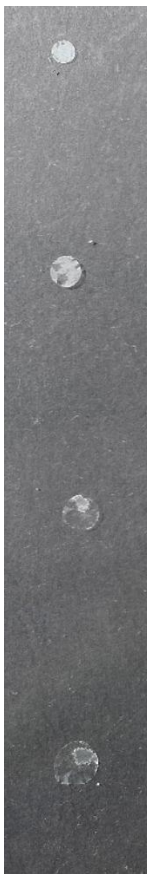
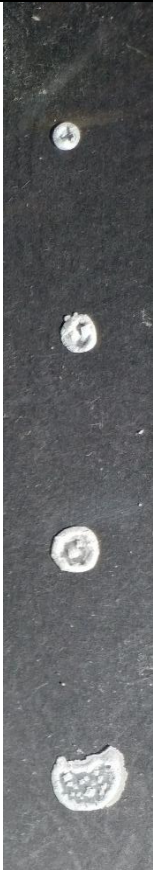
Experiment

Several hours before the lesson (the exact time depends on the freezer settings), the teacher allows part of the saline solution to freeze partially. Time for freezing and access to a freezer should therefore be planned in advance. If each student group prepares its own saline solution, it is useful to divide it into two containers. One container serves as the reference sample, while the other is partially frozen. To minimize evaporation and facilitate handling, sealable containers are recommended. (Note: If the freezer temperature can be controlled, setting it to approximately -5°C and stirring the solution occasionally will produce relatively pure ice. If the freezer operates at a much lower temperature (e.g. -20

Module 3: Climate Science Experiments

°C), a cryohydrate—a mixture of ice crystals and concentrated saline solution—will form, making it impossible to separate the ice from the remaining brine.)

For younger or less experienced students, comparing the size of the evaporation residues is recommended. Older or more experienced students may use different comparison methods, creating an opportunity for a valuable discussion about the accuracy and limitations of each method.

			
Tap water	Saline solution	Melted ice formed from the saline solution	Unfrozen part of the saline solution

3. Demonstration of the effect of glacier melting on ocean currents

Module 3: Climate Science Experiments

The teacher fills two identical transparent containers (e.g. glass jars) to the brim, one with cold water and the other with warm water. To make the temperature difference more visible, food colouring may be added—for example, blue for the cold water and red for the warm water.

a) The teacher covers the container with warm water using a piece of stiff cardboard, carefully inverts it, briefly holds the cardboard in place until it adheres to the container, and then places the inverted container on top of the container filled with cold water. The cardboard separating the two containers is then carefully removed. Students observe the demonstration and record or sketch their observations.

b) In the second demonstration, the arrangement is reversed. The teacher covers the container with cold water using a piece of stiff cardboard, carefully inverts it, briefly holds the cardboard in place until it adheres to the container, and then places the inverted container on top of the container filled with warm water. The teacher then carefully pulls the cardboard slightly to create a narrow gap along the inner edge of the containers, allowing the warm and cold water to come into contact. Students again observe the demonstration and record or sketch their observations.

The students' task is to explain the observed differences either

- a) individually (in writing or by recording a voice message), or*
- b) using the Think–Pair–Share strategy. Students first think individually about their explanation. They then work in pairs to formulate a common explanation. In larger classes, pairs may join another pair to compare their ideas and agree on a shared explanation before presenting it to the whole class. Finally, each group presents its explanation to the class.*



Module 3: Climate Science Experiments

Accessibility & Inclusion

Students work collaboratively in groups and may choose a role within the group that best suits their strengths. The activity is designed so that students can carry out both qualitative and quantitative measurements, depending on their abilities. The use of a concept cartoon encourages students to express their ideas without fear and to engage in constructive scientific discussion. It also helps them focus any criticism on the claims and supporting arguments rather than on the person presenting them.

Using the Think–Pair–Share strategy gives students time to think about and formulate their own ideas and conclusions before discussing them in the safe environment of a small group and only then sharing them with the whole class.

Inclusion can be further supported by adapting the student worksheets (e.g. by adding illustrations, checklists of tasks, or providing more space for written responses).

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Module 3: Climate Science Experiments

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Assessment	
Formative Assessment	<i>During the activity, the teacher continuously provides feedback and encouragement. The teacher observes:</i> - <i>the planning of the experiment,</i> - <i>the formulation of hypotheses,</i> - <i>collaboration within the group,</i> - <i>the use of scientific arguments and appropriate scientific terminology.</i>
Summative Assessment (if applicable)	<i>The following may be assessed:</i> - <i>the quality of the experimental design investigating the effects of glacier formation and melting on ocean salinity,</i>

Module 3: Climate Science Experiments

	- the group presentation explaining the demonstration of the effect of glacier melting on ocean currents.
Student Self-Assessment	At the end of the lesson, students complete the following: - Today I understood that... - What surprised me most was... - Next time I would like to... or indicate their self-assessment using the following scale: ☐ I understand completely. ☐ I understand with a little help. ☐ I need further explanation.
Peer Feedback	When using the Think–Pair–Share strategy, students naturally provide one another with feedback that supports learning.
Documentation, Evidence & Follow-Up	
Evidence to Collect	- student worksheets, - students' models illustrating the effects of melting land ice and sea ice on sea level, - students' experimental designs investigating the effects of glacier formation and melting on ocean salinity, - experimental data:

Module 3: Climate Science Experiments

	<i>If students determine the density of the solutions, they are expected to repeat the measurements and record all results in a table.</i> <i>If students compare salt concentrations visually by examining evaporation residues, they are expected to compare several residues obtained from equal volumes of each solution and to photograph the results.</i>
Impact Tracking	<i>Throughout the series of activities, the teacher may monitor:</i> - <i>students' understanding of the complex consequences of glacier melting (students may be asked before the activity to list the environmental consequences of glacier melting, and the number and connections of the identified effects can then be compared),</i> - <i>their ability to design an experiment,</i> - <i>the quality of the recorded data,</i> - <i>the quality of the interpretation of the experimental data,</i> - <i>the quality of the explanation of the demonstration illustrating the effect of glacier melting on ocean currents.</i>
Dissemination	<i>The results may be presented:</i> - <i>on a noticeboard in the science or physics classroom,</i> - <i>on the school's website,</i> - <i>in the school magazine,</i> - <i>during Earth Day or a thematic project day.</i>

Module 3: Climate Science Experiments

Next Steps

The activities can be extended by:

- *determining the temperature profile of the water in a container containing ice (using a thermal imaging camera or a series of digital thermometers),*
- *investigating the impacts of glacier melting on biodiversity and on the lives of people living in Arctic regions through information search and literature review.*

Teacher Reflection

Were the learning objectives achieved?

What were the students' initial conceptions?

What questions did the students ask?

Were the students able to design the experiment independently?

Which consequences of glacier melting surprised the students the most?

What should be modified if the activity is implemented again?



Module 3: Climate Science Experiments

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