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STEAM4Climate Teacher’s Guide
to Project-Based Climate Education

Project: From measurements to meaning – studying ecosystems in the STEAM way

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1. Learning Overview

This project invites students to explore biodiversity and ecosystems through a hands-on, interdisciplinary STEAM approach. By designing and monitoring self-contained “ecosystems-in-a-jar,” participants combine scientific inquiry with engineering creativity, digital technology, and data analysis to better understand how life interacts with its environment.

Using a set of sensors with a data acquisition module, students measure key environmental parameters like temperature, humidity, CO_2 levels, light intensity, or soil moisture. They build a foundation in scientific methods by calibrating sensors, forming hypotheses, and analyzing real-time data. The project explores the invisible dynamics of life, including response to man-made intrusions.

From sealed terrariums and aquatic ecosystems to fungal microhabitats and hydroponic systems, each student-designed jar becomes a living laboratory. By bridging disciplines, this project nurtures curiosity, systems thinking, and environmental awareness.

Key Concept: Getting acquainted with the datalogging of a set of environmental parameters and developing confidence in interpreting

Duration:

Number of Sessions: at least two,

Target Age Group: high school, 15+

2. Learning Objectives & Methodology

Getting acquainted with the datalogging of a set of environmental parameters and developing confidence in interpreting

This guide integrates physics and biology to explore the impact of wet bulb temperature on the human body. Teachers are encouraged to blend hands-on experiments with theoretical discussions, guiding students through:

1. **Introductory experiments:** Hands-on experiments …
2. **Data Analysis:** Use
3. **PBL Self-science:** Encourage discussions

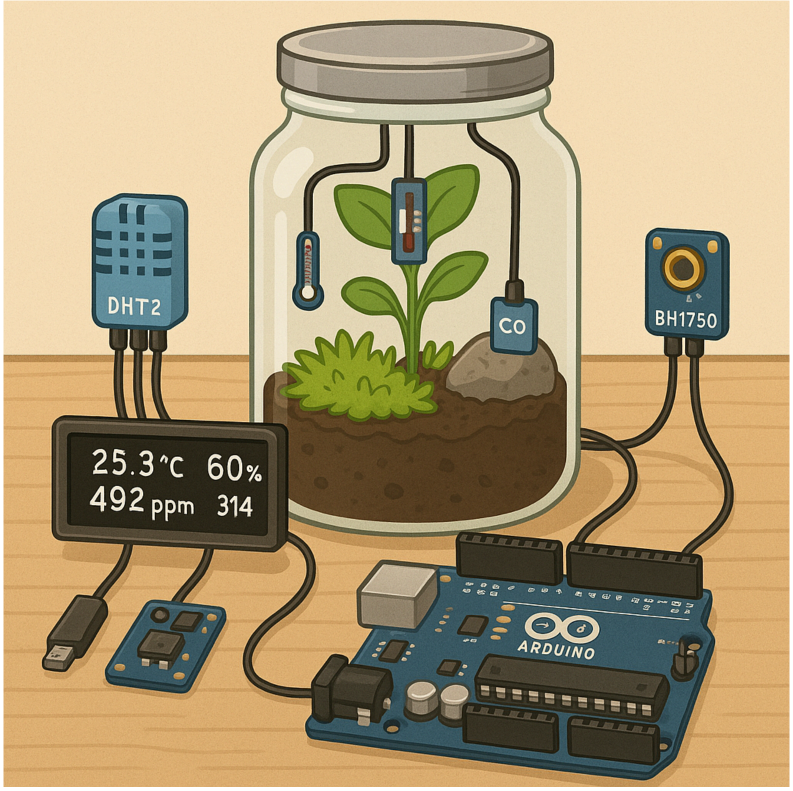
3. A “Low Floor, High Ceiling, Wide Walls” Approach

In STEAM4Climate, we adapted an approach that empowers students to explore ecosystems and biodiversity with various sensors, regardless of their technical abilities.

- **Low Floor:** Beginners can easily get started with basic tools like a pre-built Arduino sensor kit, simple jars, and everyday materials (soil, moss, water). No prior coding or electronics experience is required in this scenario if *STEAM4Climate Environmental Kit* is used. Quantitative observations will give students insights into the ecosystem dynamics. Also, for every scenario, code is available for copying.
- **High Ceiling:** Advanced learners can incorporate more sophisticated sensors (for example NO_2, CH_4, and ethanol sensors, apart from just CO_2) for appropriate scenarios and self-program their projects. For top-tier students qualitative analysis is possible. They can be encouraged to run additional experiments, like observing the effect of overfertilization of soil leading to nitrogen compound emission or studying the long-term sustainability of sealed biospheres.

- **Wide Walls:** The possibilities are broad – students can choose to model different ecosystems (soil-based ecosystems, hydroponic systems, aquatic environments), sealed or open, aerobic or anaerobic. Each jar becomes a unique scientific and creative composition, encouraging experimentation with multiple iterations. Ultimately, why stick to the jar, if measurements can be done outdoors, in your garden compost or nearby wetlands?

Whether indoors or in the field, every learner's path is different – and every ecosystem jar tells its own story. We hope that immersive experience promotes curiosity and a lasting appreciation for the complexity of life and the environment.



Materials

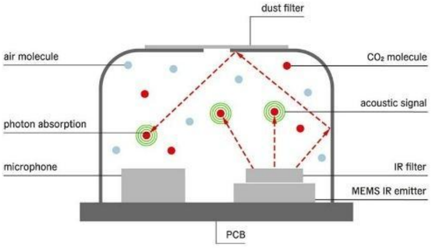
4. Materials Included in Toolbox for basic version

- CO2 sensor (Gravity: SEN0536)
- DAQ module (Gravity: SCI DAQ Module)
- Battery booster
- Two batteries
- Wires: Double-headed PH2.0-4P, battery in (self-made)

Basic sensors – temperature, humidity, CO_2 concentration

Temperature and humidity sensors are usually integrated units (like DHT11 or DHT22). Even though they can be bought and connected separately, using a board with embedded detectors is more convenient, reducing the need for wire management. The basic sensor for CO_2 concentration we recommend as cost-effective is **SCD41**:

"The SCD4x is Sensirion's second generation series of optical CO2 sensors. The sensor series builds on the photoacoustic NDIR[1] sensing principle and Sensirion's patented PASens® and CMOSens® technology to offer accuracy at an attractive price and small form factor. SMD assembly allows cost- and space-effective integration of the sensor combined with maximal freedom of design. On-chip signal compensation is realized with the built-in SHT4x humidity and temperature sensor."[2]



"SCD41 sensor detects the amount of energy that is absorbed by CO2 molecules. When pulsing the infra-red emitter, CO2 molecules absorb infrared light periodically. This causes additional molecular vibration resulting in a pressure wave inside the measurement chamber. The higher the CO2 concentration, the more light is absorbed, and thus the greater the amplitude of this acoustic wave becomes. A microphone inside

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[1] NDIR – Non-Dispersive Infra-Red

[2] https://sensirion.com/products/catalog/SCD41

the gas chamber measures this, from which the CO2 concentration can then be calculated.”[3]

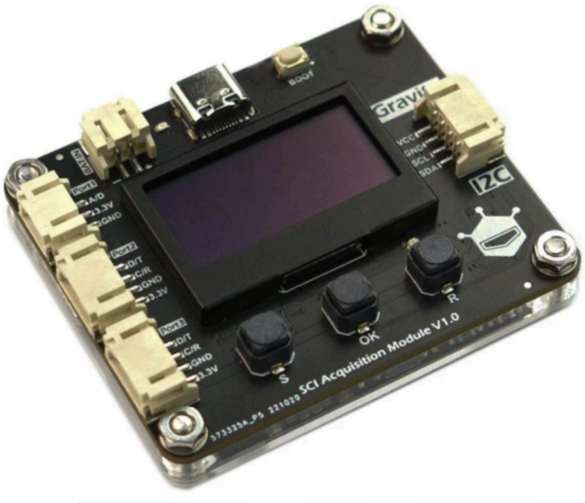
Various manufacturers sell this sensor using slightly different designs of PCB boards. To avoid the need for soldering and to use a consistent set of sensors, we decided to use **the Gravity platform designed by DFRobot company**. Therefore, we decided to implement the project using the **DFRobot SEN0536** module.

*Figure SEQ Figure * ARABIC 3. SEN0536 module for CO2, T and H (source: manufacturer)*

Gravity: Science Data Acquisition (SCI DAQ) Module

Specification[4]:

- Operating Voltage: 3.3-5.5V DC
- Operating Current: 40mA
- Output Signal: I2C (0x21-0x23)
- Input Interface: 1 x Digital/Analog, 2 x I2C/UART
- Onboard Storage: 16M
- RTC Battery: CR1220
- Screen Info: 1.3 inches OLED
- Product Dimension: 62×52×13mm



5. Other components for basic version

- Sealed container (1l jar or plastic bottle)
- Pack of dry yeast (5g)
- Pack of baking soda

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[3] https://wiki.dfrobot.com/SKU_SEN0536_Gravity_SCD41_Infrared_CO2_Sensor

[4] https://www.dfrobot.com/product-2655.html

- Pack of citric acid or vinegar
- Sugar
- Tap water
- Piece of soil

6. Components for the extended version

According to the “wide walls” approach, there are many options to expand the project with the use of the provided SCI DAQ module, as it supports various sensors relevant to study environments:

- analogue soil moisture, ambient light sensor
- non-contact IR Temperature Sensor,
- water quality: pH, electrical conductivity, TDS, waterproof thermometer
- gas detectors (electrochemical)

In case of simultaneous use of many sensors, an additional “I2C hub” is required, but there are some technical difficulties – we recommend using a separate DAQ instead. The full list of supported equipment is available on the manufacturer's website:

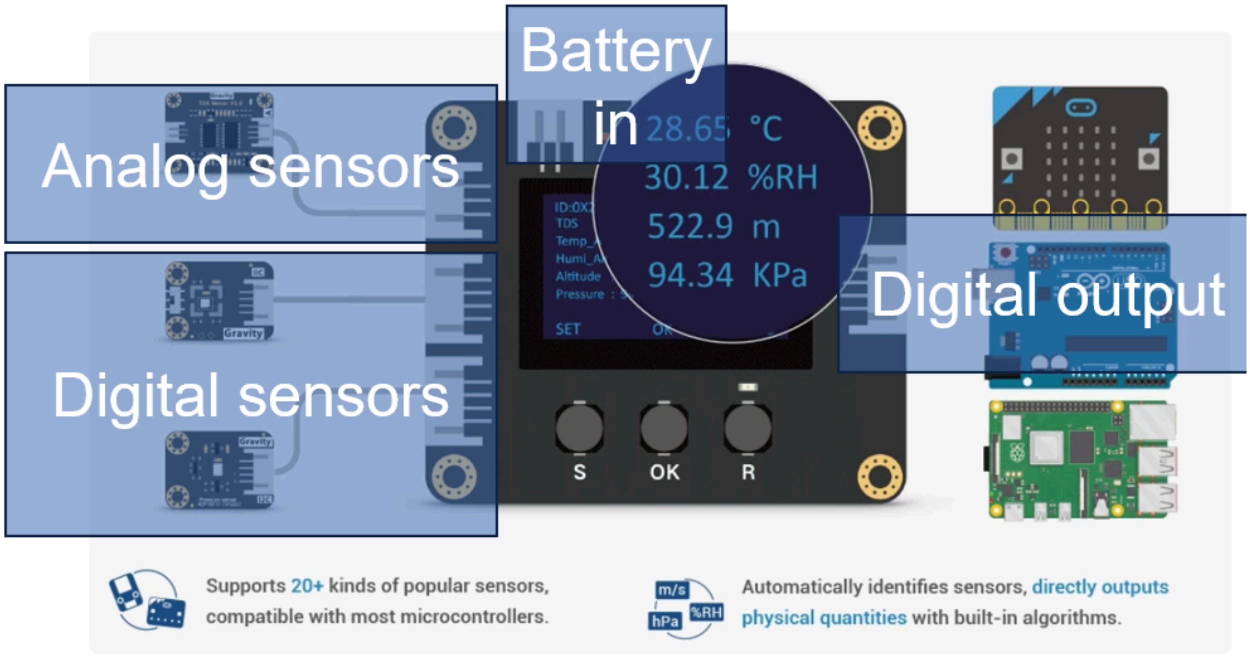
https://www.dfrobot.com/product-2655.html

Activity Instructions

7. Pre-Activity Preparation

7.1 Connection equipment

SCI DAQ module needs to be powered – in our setup, we are using a battery with a step-up booster; therefore, two AA batteries are enough to power the DAQ. The 2-pin battery socket is located above the display, while our sensor should be connected via a 4-pin socket to the left of the display. Alternatively, it can be powered via USB-C cable (connected to a power bank – not included):[5]



Activity for students:

- Connect and read the CO2 concentration (in ppm, parts per million)
- Compare values displayed indoors and outdoors
- Check how the sensor reacts to your breath

7.2 Datalogging

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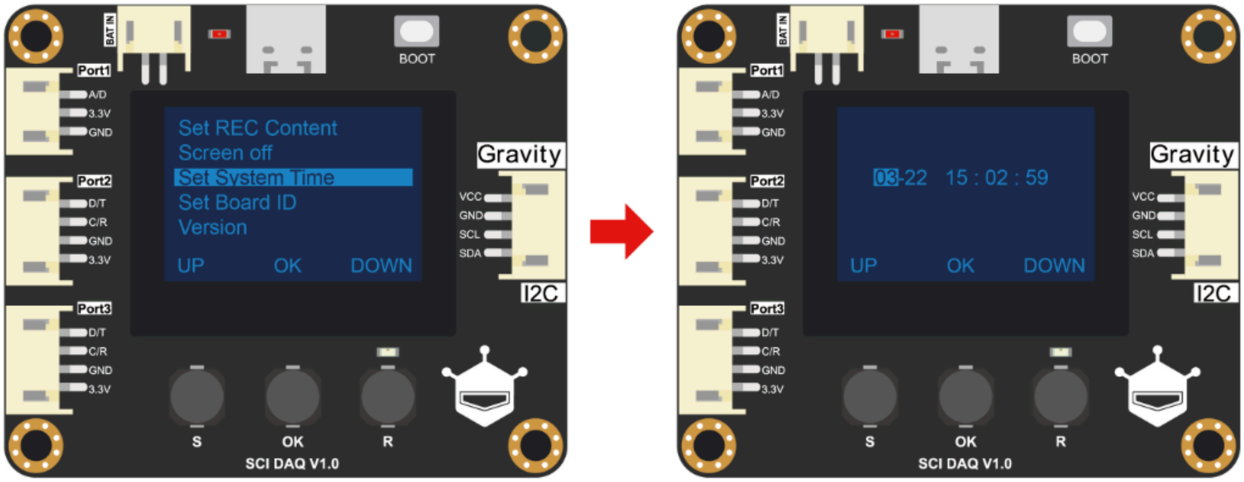
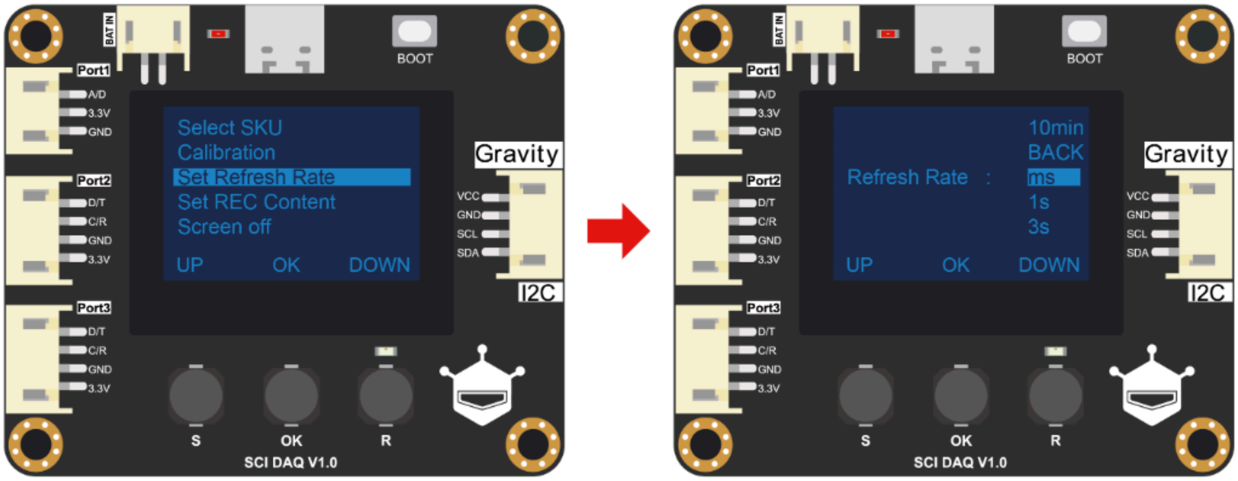
[5] Picture in the back – manufacturer website: https://www.dfrobot.com/product-2724.html

To record the measurements, two setups are expected:

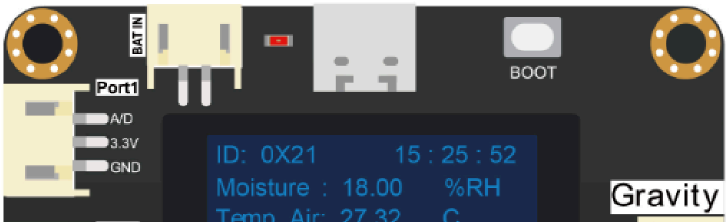
Setting System Time:



Setting the refresh rate:

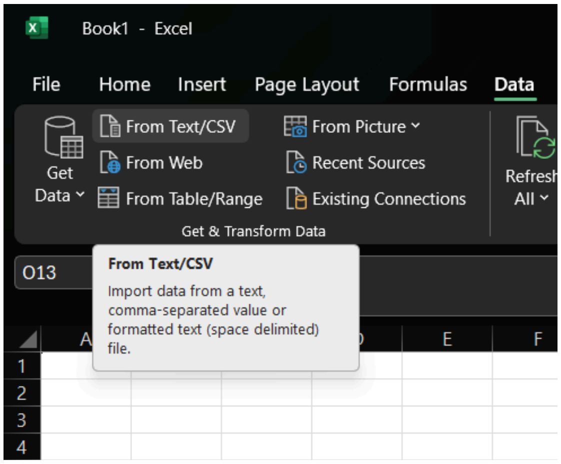


With the right button, datalogging can start.



The blinking of the yellow diode is to indicate that the recording is in progress.

After recording the data, the CSV file is created with “,” as a separator. To read the file we recommend use of Excel (or similar software), following the steps: Data -> Read from CSV -> Load.



From Text/CSV

Import data from a text, comma-separated value or formatted text (space delimited) file.

7.3 Interactive story

Click here to explore an interactive activity on…

8. Activity Execution

Below is a list of exercises on a different level of complexity. It is up to a teacher to choose which exercises to run with a particular group of students.

8.1 Making sense of ppm

Objective:

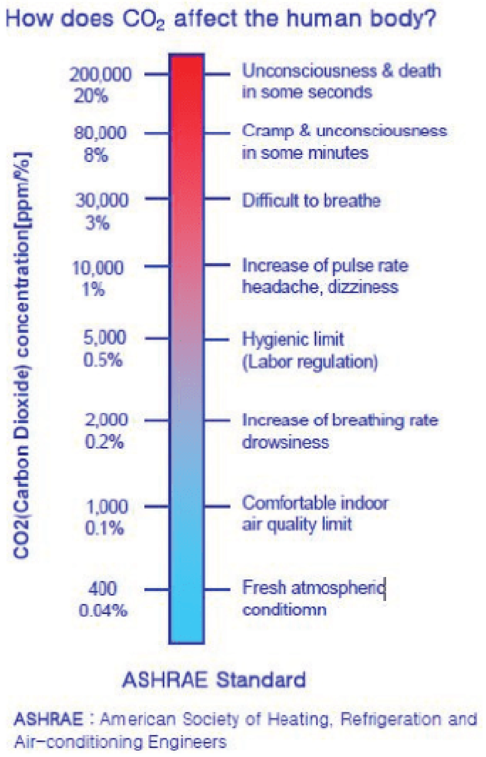
To understand what “ppm” means, measure CO_2 levels in different environments, and analyze how concentration changes over time.

Procedure:

1. Turn on the CO_2 sensor and wait a few minutes until the readings stabilize (warm-up).
2. Start recording data with the detector. While it runs, observe the values live on the display.
3. Take the sensor around:
    - Measure in the classroom.
    - Step outside and compare outdoor values.
    - Breathe on the sensor briefly in open air (note the quick spike).
    - Place it in a closed jar/box, exhale inside, and cover (note how long the values stay high).
4. After finishing the walk/experiments, stop the recording.
5. Connect the sensor to a computer via USB-C. Locate the most recent CSV file (separator = “,”), copy it to your device, and free up logger memory.
6. Make a scatter plot: CO_2 concentration (ppm) vs. time (s).
7. Compare the graph with your observation notes:
    - When you moved indoors/outdoors,
    - When you breathed on the sensor,
    - How quickly the values rose and fell (detector inertia).

What does this have to do with climate?:

- Outdoor air normally contains ~400–450 ppm CO_2, while indoor spaces can reach 1000–2000 ppm without ventilation.
- Globally, CO_2 levels before the Industrial Revolution were about **280 ppm**. Today they exceed **420 ppm**, a ~50% increase in just 200 years – the fastest rise in Earth's recent history. This extra CO_2 traps more heat in the atmosphere, amplifying the greenhouse effect and driving climate change.
- Human breath contains ~40 000 ppm CO_2, showing how even small emissions in a confined space quickly accumulate.
- By recording, plotting, and linking measurements with observations, students experience how invisible gases can be tracked — exactly how climate scientists monitor the planet's changing atmosphere.



[6]

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[6] https://gasalarm.com.au/importance-of-co2-measurement-inside-meeting-rooms-classrooms-offices-etc/

8.2 Chemical production of CO2

Objective:

To demonstrate how chemical reactions can produce large amounts of CO_2, and to measure this gas using both mass changes and direct sensors.

Procedure:

1. Prepare 5 g baking soda ($NaHCO_3$) and 3,8 g citric acid ($C_6H_8O_7$) dissolved in 30–50 ml of water (vinegar can be used as an alternative).
2. Place the container with the acid solution on an electronic balance and tare it (set to zero).
3. Add the baking soda and observe: bubbling in the liquid and decreasing mass on the display. Record the changes over time.
4. Repeat the experiment in a jar with a lid:
    - Attach the CO_2 sensor under the lid (above the liquid).
    - Start data recording, add the baking soda, and close the jar (leave a small gap for safety).
    - Record the rapid increase of CO_2 concentration for at least several dozen seconds.
5. Export the data file (CSV) and make a scatter plot of CO_2 concentration (ppm) vs. time (s). Compare with your notes from direct observations (bubbles, mass change).

What does this have to do with climate?:

- The reaction clearly shows the release of CO_2 gas. The “disappearing” mass on the balance and the rising sensor readings are two perspectives on the same process: invisible gas leaving the liquid into the air.
- On a global scale, industrial chemical processes are major CO_2 sources. Burning fossil fuels (coal, oil, gas) adds ~35–37 billion tons of CO_2 annually. Cement production adds another ~2.5–3 billion tons (≈7–8% of global emissions).

- Just like in the jar, the Earth's atmosphere is a closed space: the CO_2 we emit accumulates.

Optional – calculations:

Step 1: Molar Masses

Compound	Formula	Molar Mass (g/mol)
Baking Soda	$NaHCO_3$	84.01
Citric Acid	$C_6H_8O_7$	192.12
Carbon Dioxide	CO_2	44.01

Step 2: Moles of Baking Soda (given)

$$n_{NaHCO_3} = \frac{5\ g}{84.01\ g/mol} \approx 0.0595\ mol$$

Step 3: Stoichiometry

From the balanced reaction:

- 1 mol citric acid reacts with **3 mol $NaHCO_3$**, so:

$$n_{citric\ acid} = \frac{1}{3} x 0.0595\ mol \approx 0.01983\ mol$$

Step 4: Mass of Citric Acid Needed

$$m_{citric\ acid} = n_{citric\ acid}\ x\ M_{citric\ acid} = 0.01983\ mol\ x\ 192.12 \frac{g}{mol} \approx 3.81\ g$$

Step 5: CO_2 Produced

From the balanced reaction:

- The reaction produces **3 mol CO_2 per 3 mol $NaHCO_3$**, so:

$$n_{CO_2} = 0.0595\ mol$$

$$m_{CO_2} = 0.0595\ mol\ x\ 44.01 \frac{g}{mol} \approx 2.62\ g$$

Summary:

- One needs **3.81 g of citric acid** to react with **5 g of baking soda**.
- One will produce approximately **2.62 g of CO_2** gas.

8.3 Biological production of CO2 – yeast and the role of temperature

Objective:

To observe CO_2 production during fermentation by yeast and connect biological processes to greenhouse gas emissions.

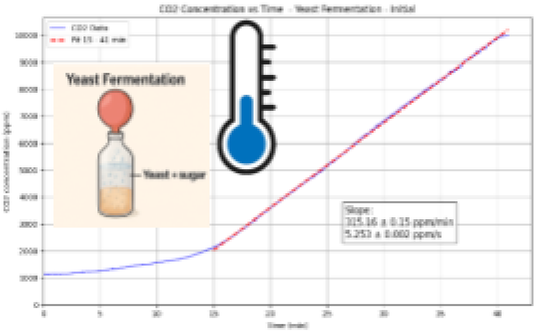
Procedure:

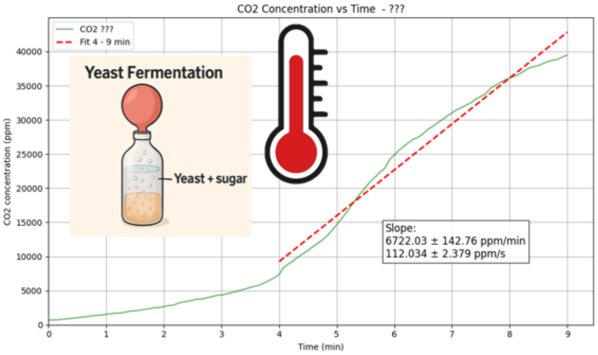
1. Prepare:
   - 1 packet of dry yeast (~7 g),
   - 1 teaspoon sugar,
   - warm water (30–40 °C), around 100 ml
   - a plastic bottle or jar,
   - a balloon for bottle or lid for a jar,
   - a CO_2 sensor with DAQ,
   - thermometer to measure water temperature.
2. Add yeast and sugar to the container, pour in warm water (measure the initial temperature), and stir.
3. Close the container:
   - If using a balloon, place it over the neck so it can inflate with gas (this is a qualitative demonstration of gas production for younger students)
   - If using a lid, attach the CO_2 sensor under the lid (above the liquid) and start recording data.
4. Observe for 15–30 minutes:
   - foam appears on the surface,
   - the balloon inflates,
   - the CO_2 sensor shows a gradual rise (often several thousand ppm).
5. Export the data (CSV) and make a scatter plot: CO_2 concentration (ppm) vs. time (s). Compare the graph with notes of what you saw happening (foam, balloon inflating).

Extended version:

Ask students to prepare several containers with water at different temperatures (e.g. cold ~10 °C, room temperature ~20 °C, warm ~30–40 °C, hot ~50 °C). Add the same amount of yeast and sugar to each. Record CO_2 concentration over time with the sensor (or compare balloon inflation). This extension lets students test how temperature affects the rate of biological CO_2 production and identify the "optimum range" for yeast activity. It links directly to climate science, since temperature strongly regulates biological processes such as respiration, decomposition, and microbial activity in soils.

In the example below, the rate of CO2 release changes over 20 times because of changing the water temperature:





What does this have to do with climate?:

- Fermentation is a biological process where yeast breaks down sugar into alcohol and CO_2. The experiment shows that living organisms can be important CO_2 sources.
- On a global scale, similar biological processes contribute to greenhouse gas emissions in agriculture and food production. Farming, livestock, and land use changes emit about **6 billion tons of CO_2 equivalent annually** (~15–20% of human-caused greenhouse gases). Agriculture is one of the major sectors responsible for global warming.

- Dramatic ecological events remind us of the sensitivity of ecosystems: for example, the **mass die-off of saiga antelopes in Kazakhstan**[7] in 2015, where climate conditions enabled bacterial infection that killed over 200,000 animals. Such cases illustrate how subtle shifts in temperature and humidity can trigger large biological feedbacks, just as small microbial processes in this experiment scale up to affect global climate.

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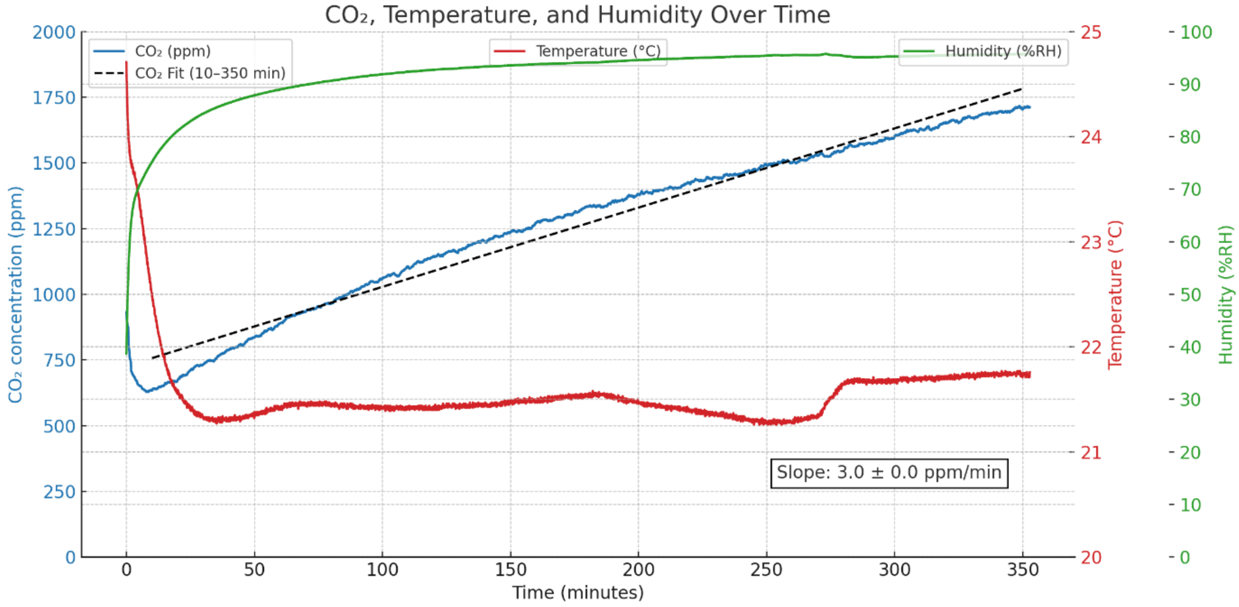
[7] https://www.theguardian.com/science/animal-magic/2016/apr/14/mass-death-saiga-antelope-kazakhstan-bacterial-infection

8.4 Biological production of CO2 – soil

Objective: to…

Procedure: take…

What does this have to do with climate?:



8.5 Introduction to Smart Farming

“How often should you water the plant?”

Objective: to…

Procedure: take…

What does this have to do with climate?:

8.6 Building a self-sustaining sealed ecosystem

PBL challange

Objective: to…

Procedure: take…

What does this have to do with climate?:

Post lesson follow-up & summary

9. Discussion Topics

…

10. Assessment

11. Extensions

11.1 Studying transpiration with potometer

11.2 Measurements of other gases and parameters