Coding H_2O

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<Info>

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<Disciplines> physics, environmental science, chemistry, computer science, mathematics

<Age level of the students> 13–15

<Hardware> Arduino[1], Calliope mini[2], Raspberry Pi[3]

<Language> Arduino[4], Python[5], block programming

<Programming level> medium

<Summary>

The students will design, build and test a solar still to purify water. They will program sensors to measure the efficiency of their solar stills.

<Conceptual introduction>

We will cover the following physics concepts:

- ↳ Changes of state (specifically, evaporation and condensation) and their main characteristics
- ↳ Factors that affect the evaporation process (temperature, surface area, etc.)
- ↳ Effects of heat: changes of state
- ↳ Difference between renewable (solar energy) and non-renewable energy sources
- ↳ IR radiation and its role in transporting heat from the sun
- ↳ Radiation and its reflection on certain surfaces
- ↳ Methods for separating mixtures
- ↳ Solutions: what they are, concentration (g/L and mass percentage, etc.)

Depending on the students' prior knowledge, they will discover some of these concepts by themselves, while others will have to be explained by the teacher and experimentally validated by the students.

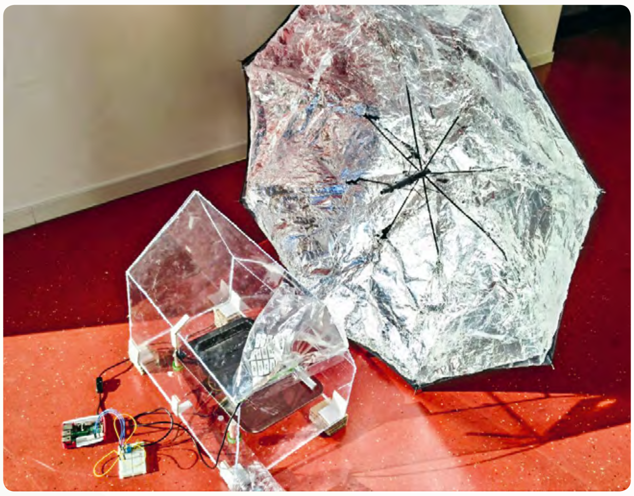
The aim of our project is to design and build the most efficient solar still to purify water. Only solar energy may be used. First, the efficiency of the solar still will be determined by calculating the volume percentage of the purified water that is obtained. After this, the students will program different sensors to analyse the effectiveness of their designs.

The main task of this activity is to program sensors, so the teachers will need programming skills and some basic hardware knowledge to do so.

They will need to know how to build the circuit required to connect the sensors to the microcontroller board. Depending on their skill level, they can either use block programming (Calliope mini[2], Snap4Arduino[6], etc.) or text programming (Arduino[4], Python[5], etc.) to program the sensors.

<What the students/teachers do>

This unit consists of three parts: designing and building a solar still, coding sensors and testing the solar still.



Solar still

<Part one: Designing and building the solar still>

The project will be presented to the students and they will test their initial example of a solar still as a class by measuring the amount of cleaned water collected and calculating the efficiency of this design. While doing so, they will review physics concepts such as changes of state, solutions and solar energy.

Next, the students will be encouraged to improve this initial design. To do so, they will have to work in groups (2–3 students per group). This phase of the unit can be divided into different tasks:

1. The students will search for information about solar stills, how they work, different designs already in use, etc. During the research process, they will be asked to reflect on the following questions:
   a. Evaporation process: what are the main factors affecting this process? Think about the surface where you are going to place the dirty water. Is it better to have a wide or a narrow surface, a larger depth or a smaller one? Does the colour of the container matter?
   b. Condensation process: what is necessary to produce condensation? Do you need to design a large or a small surface for water condensation? How are you going to make the clean water move to the point where you wish to collect it?

c. Radiation process: how can you maximise the IR radiation hitting your solar still? How can you reach the maximum temperature possible in your solar still? Consider using a surface covered with aluminium foil to reflect the sunlight into the solar still.

2. The groups will create their designs and explain them to the teacher.
3. Once the teacher has approved the design, the students will be asked to find the appropriate materials (at school, at home, order online, etc.) and build their still.
4. The students will determine the efficiency of their solar stills without sensors. Using a graduated cylinder, they will not only measure the volume of dirty water but also the volume of clean water collected and apply the following mathematical equation:

$$Efficiency = \frac{volume\ of\ water\ collected}{volume\ of\ dirty\ water}$$

A step-by-step guide including tasks and questions for the students is provided for the second and third parts of this activity.

The aim is to give the students different choices with regard to sensors, programming languages and hardware, but this also depends on each individual school/class (available materials, programming language knowledge, etc.).

<Part two: Coding sensors>

Only the best solar stills will be tested using sensors. In this part, you will need to:

1. Select the microcontroller board, programming language and sensors that you are going to work with. Answer the following questions to help you make the best decision:
   a. Will you use block programming or text programming? If you choose block programming, consider using a Calliope mini[2] or, alternatively, program a Raspberry Pi[3] with Scratch[8]. In case you opt for text programming, you could use an Arduino[1], or code in Python[5] for Raspberry Pi[9].
   b. Are you going to use digital or analogue sensors? If you decide on the latter, Arduino could be the best choice.

2. Choose the sensors that you want to use. To keep things simple, please select no more than two sensors. Some examples are temperature, humidity, rain and IR radiation. Before making your decision, consider the specifications of each sensor. Is the output signal analogue or is it a digital signal with only two possible values (true/false)? How does the output signal relate to the value of the parameter that you are measuring? Are they directly proportional? Does the output increase as the parameter decreases?

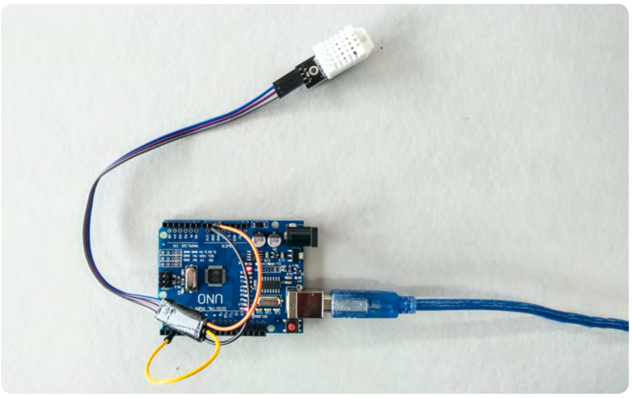
3. Build the circuit to connect your sensor to the microcontroller board. Use the additional resources provided[7] or search the Internet for examples.

4. Code the sensors. You must follow these steps:
   a. Write down what you want your program to do, considering the features of the sensors that you have selected. Do you want your program to only display the value of the measured parameter? Do you also want to show the maximum and minimum values? Does your sensor show the actual value of the parameter or do you need to make any calculations?
   b. Write your program. Do not forget to write comments on your code. You can use the additional resources provided by your teacher as a guide.[7]

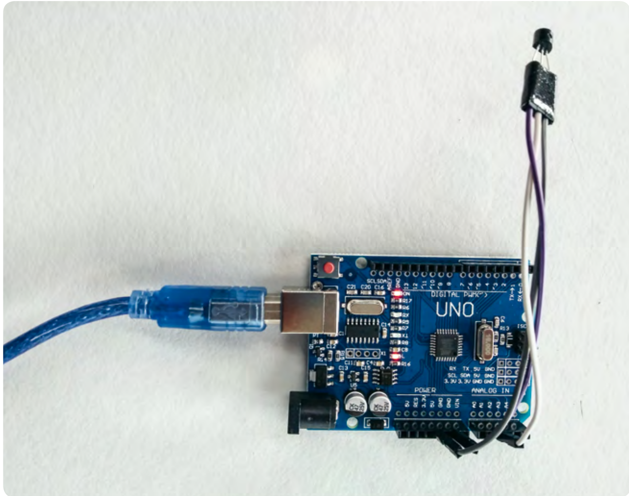
5. Test your code. Does the program work as expected? Examples:
   ↳ You can measure the amount of infrared radiation that reaches the solar still with a flame sensor and an Arduino UNO[1]. If you are using a surface covered with aluminium foil, use this sensor to test whether the radiation is reflected into the solar still.

Flame sensor

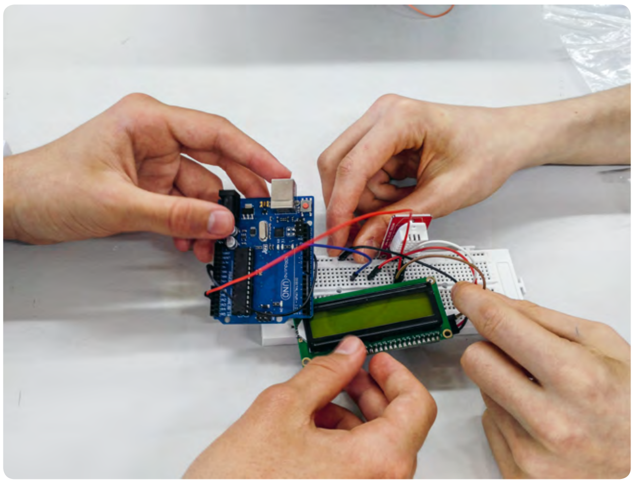
   ↳ You can record the maximum temperature and the relative humidity reached inside the solar still with the DHT11 or DHT22 humidity and temperature sensor and your Arduino UNO.



Arduino with humidity sensor

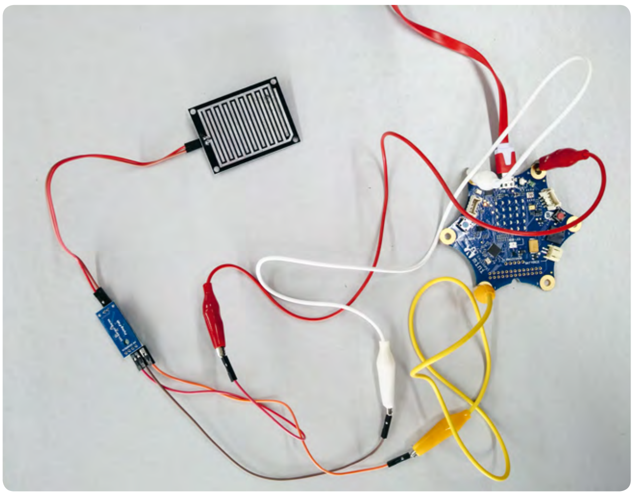


Arduino with temperature sensor



Arduino with LCD display and humidity sensor

- You can write a Python 3 program to determine the time that it takes for the first water drops to condense with the FR-04 rain sensor and Raspberry Pi[3]. You can also use this sensor with a Calliope mini and program it with Snap![10] (block programming language).



Rain sensor with a Calliope mini

<Part three: Test the solar stills with sensors>

Your team has to use the programmed sensors to test and compare your design with another one. The solar stills have to work under the same conditions and use the same type of sensors for this to happen.

You will analyse the reasons why the efficiencies are different, noting key facts like the factors that affect evaporation, etc.

How to improve the efficiency of the solar still:

- Test it on a sunny day over the midday period.
- Allow your equipment sufficient time to reach the highest temperature possible.
- Make sure the solar still is airtight to avoid any loss of water vapour.
- Remove the clean water on an ongoing basis to prevent it from evaporating.
- Colour the dirty water to ensure that the solar still works properly.
- Choose a wide, black container for the dirty water.
- Use an umbrella covered with aluminium foil to reflect sunlight into the solar still.

<Results>

The first part of the activity (building the solar still) led to designs that varied greatly in their efficiency. When tested on sunny days during May/June in Spain, the best design purified 95 % of the dirty water in 24 hours. A 54 % efficiency rate was also obtained in 4 hours. Nevertheless, some stills collected no clean water at all due to various deficiencies in their design.

When applying the sensors, the students obtained the following results:

- The maximum temperature reached inside the solar stills after one hour on a sunny day was 65 °C.
- The influence of the colour of the container on the dirty water was analysed. Upon comparing a white and a black container left in the sun for a few minutes, the temperature of the water in the black container was found to be almost 5 °C higher than in the white one.
- The relationship between the temperature of the water and the rate of evaporation was studied using the humidity sensor. The relative humidity obtained inside a solar still that contained water at room temperature was measured at 55 %. When the water was heated to 45 °C, the relative humidity increased to 98 % in just a few seconds.
- The amount of radiation reflected by a metallic surface into the solar still was measured with the flame sensor. An old umbrella covered with aluminium foil was very effective in reflecting IR radiation.

<Conclusion>

The students will use their creativity and higher-order thinking skills (HOTS) to design the most efficient solar still. This unit will also give them the opportunity to develop their critical thinking and problem-solving skills, which is very useful because the students can utilise them on a daily basis. They will learn some key physics facts (self-learning) by observing, experimenting, testing and analysing their results, instead of simply reading about them in their physics textbooks.

They will also develop computational thinking skills while coding their sensors. They will be doing physical computing (i.e. their codes will interact with the physical world). Throughout the unit, they will follow the different steps of the scientific method outlined above to develop the best solar still design and then build it with suitable materials.

It is important that every student is involved in the project tasks. Some tasks can be done individually (searching for information, collating their initial ideas about the design…) to ensure that this happens.

However, the main obstacle is that some students may not have the appropriate programming skills (which is why we have included block programming alternatives), sufficient knowledge to build the circuits (the additional resources[7] are very helpful in this regard) or may not understand how the sensors work. In addition, the materials may not be available in all schools, so they may need to be bought.

Extension activities:

- ↳ The data collected from the sensors could be stored on an SD card for further analysis.
- ↳ An LCD screen could be used to visualise the measurements.
- ↳ Internet of Things (IoT): the data collected could be sent through the Internet in real time so it is publicly available.
- ↳ Additional sensors could be used, such as CO_2 or other greenhouse gas sensors, a conductivity sensor to check whether the clean water is still salty, a pH sensor to measure the pH of the dirty and clean water, etc.
- ↳ The salinity could be measured with seawater samples.
- ↳ A method to disinfect the collected water could be added.

The students could use the solar stills to study the greenhouse effect, photosynthesis, cell respiration, ideal gases, etc. Many sensors could be used in other projects to measure physical or chemical parameters; for example, to monitor air pollution or water quality.

<Cooperation activity>

Are solar stills more efficient in countries with sunny weather? Students from different European schools could share their results, using an online map for location purposes. The salinity of the different places could be compared by taking seawater samples.

<References>

[1] www.arduino.cc/
[2] https://calliope.cc/en
[3] www.raspberrypi.org
[4] www.arduino.cc/reference/en/
[5] www.python.org/
[6] http://snap4arduino.rocks/
[7] All additional materials are available at www.science-on-stage.de/coding-materials.
[8] https://scratch.mit.edu/
[9] www.raspberrypi.org/documentation/usage/python/
[10] https://snap.berkeley.edu/

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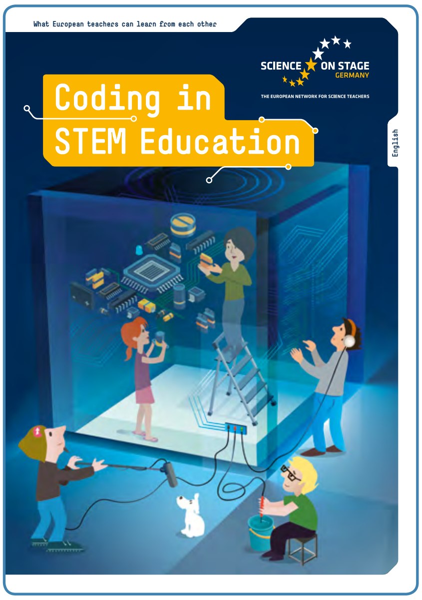

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