

Supplementary Materials: Towards a Sustainable Future through Renewable Energies at Secondary School: An Educational Proposal

Judit García-Ferrero ^{1,†} , Rosa P. Merchán ^{1,†} , José M. Mateos Roco ^{1,†} , Alejandro Medina ^{1,†}  and María Jesús Santos ^{1,*} 

1. Resources concerning Renewable Energy Week

1.1. Socrative quizzes

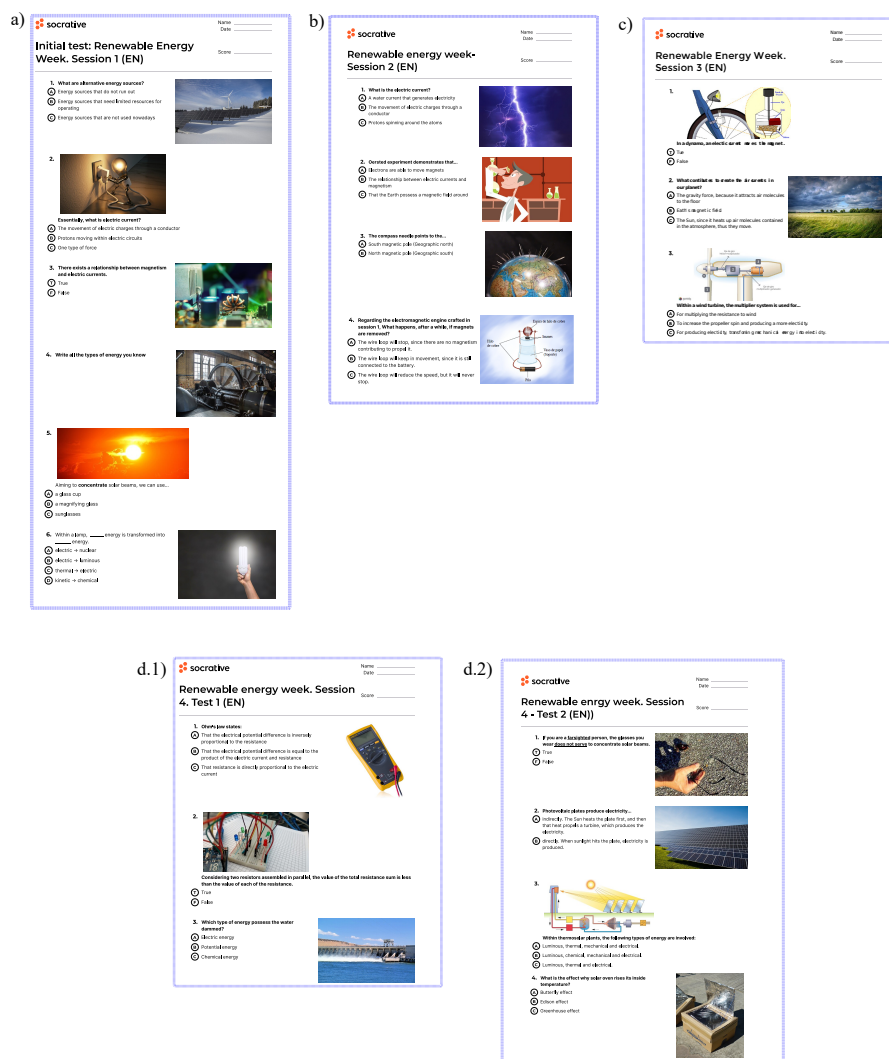



Figure S1. Socrative quizzes for *Renewable Energy Week*, a) Initial test, b) Quiz related to Session S1, c) Quiz related to Session S2, d.1) Quiz related to Session S3 and d.2) Quiz related to Session S4.

1.2. "Scientific sheets"

a) 


SCIENTIFIC SHEET: SESSION 1

Group's name: _____
 Today ENGINEERS are: _____
 Today the SCIENTIST is: _____
 Today the REPORTER is: _____

Describe, briefly and using your own words, Oersted experience.

Enumerate and write the steps your group followed for crafting the electromagnetic engine.

Which additional information have you found on the Internet about electric engines and the relationship between electricity and magnetism? (You should cite the websites where you extract the information from. Example: "Article found on BBC website")

b) 

SCIENTIFIC SHEET: SESSION 2


Group's name: _____
 Today ENGINEERS are: _____
 Today the SCIENTIST is: _____
 Today the REPORTER is: _____

Describe, in your own words, what happens when the crank of a dynamo is rotated.

Why does the paper propeller begin to rotate when the candles are fired?

Which materials and what steps followed your team to craft the wind propeller?



Write some relevant information you found on the Internet about wind energy. (You should cite the websites where you extract the information from. Example: "Article found on BBC website")

c) 

SCIENTIFIC SHEET: SESSION 3

Group's name: _____
 Today ENGINEERS are: _____
 Today the SCIENTIST is: _____
 Today the REPORTER is: _____


Write the values of resistance, electric current and electric potential difference between points A-B and A'-B', recorded by the multimeter, for each circuit assembly:

a)  b) 

$R_{AB} = \dots\dots\dots$ $R_{A'B'} = \dots\dots\dots$
 $I_{AB} = \dots\dots\dots$ $I_{A'B'} = \dots\dots\dots$
 $V_{AB} = \dots\dots\dots$ $V_{A'B'} = \dots\dots\dots$

Explain the reasons why I_{AB} and $I_{A'B'}$ show different values.

What relevant information have your group found about hydroelectric energy? (You should cite the websites where you extract the information from. Example: "Article found on BBC website")

d) 

SCIENTIFIC SHEET: SESSION 4

Group's name: _____
 Today ENGINEERS are: _____
 Today the SCIENTIST is: _____
 Today the REPORTER is: _____

Explain why you can make a campfire with the glasses of a farsighted person (not seeing well close-up), in a sunny day.

Briefly explain how a Stirling engine works.

Describe the material and the steps your team followed to craft the solar oven.

Write some curious information your group found on the Internet about solar energy. (You should cite the websites where you extract the information from. Example: "Article found on BBC website")

Figure S2. Scientific sheets designed for *Renewable Energy Week*, a) Session S1 sheet, b) Session S2 sheet, c) Session S3 sheet and d) Session S4 sheet.

1.3. Final survey

Survey: Your opinion about Renewable Energy Week

This is an anonymous survey. Try to answer with honesty.

1. What **grade** would you **give** Renewable Energy Week, from 0 to 10?
(0: I did not like it anything; 10: I really enjoyed it)

2. What was **your favourite part**?
(Example: experiments, crafting the projects, session S1, work with my team...)

3. What is the **part** that **you liked the less**? (Example: experiments, crafting the projects, session S1, work with my team...).

4. What **would you change** within the activities performed in the Renewable Energy Week?

5. Do you have **some idea to be included** next year in the Renewable Energy Week?

Figure S3. Session S4. Final survey about *Renewable Energy Week*

2. Scientific basis, materials and experimental methods

a) **Experiment: Potato battery**

Scientific basis
This basically consist on building a battery by using potatoes and wires for turning on a LED. Electric current generated comes from chemical reactions produced at the electrodes, as a consequence of the potential difference between zinc and copper metals.

Anode (Zinc plated nail) \longrightarrow Oxidation reaction $Zn \rightarrow Zn^{2+} + 2e^{-}$

Cathode (Copper coin) \longrightarrow Reduction reaction $Cu^{2+} + 2e^{-} \rightarrow Cu$

Material

- 4 coins
- 1 m of copper wire
- 1 LED of 3V
- 4 zinc plated nail
- 4 potatoes

Experimental method
For each potato, hit a zinc plated nail on one end and a coin on the other. The coin and the nail of the next potato must be connected by a wire (repeat for all potatoes). Finally, connecting the nail of the first potato to one LED extreme, and the coin of the last potato to the other extreme.

b) **Experiment: Low-cost compass**

Scientific basis
Due to the Earth's magnetic field, our planet behaves as a giant magnet. Thus, it will influence any compass, including a hand-made one. When a magnet is passed near a metal, its magnetic domains get reorganized, turning into another magnet.

Material

- 1 tray
- 1 or 2 needles
- 1 cork bung/porexpan
- A cup of water

Experimental method
Pass the magnet near the needle, always in the same direction. Pass the needle through a cork bung and let it float over a tray filled with water. Check if it points to the North, comparing its direction with a commercial compass.

c) **Experiment: Oersted experience**

Scientific basis
Oersted's law, or Oersted's Law states that when a steady electric current passes through a wire it creates a magnetic field around it.

Material

- 3 or 4 neodymium cylinder shaped magnets
- Metal bar
- Support
- A piece of thread for the magnets
- 5V battery
- 2 alligator clip wires

Experimental method
Fix the magnets to the thread, and held it by a support. Put the metal bar (conductor) parallel and near the magnets. Connect the alligator clip wires to the battery and to the conductor. Check how the magnets move when electricity passes through the conductor.

d) **Project: Electromagnetic engine**

Scientific basis
Biot-Savart Law: It states that an electric current passing through a conductor generates a magnetic field around it. Concretely, the magnetic field created at the centre of a circular loop, can be expressed as:

$$B = \frac{\mu_0 \cdot I}{2 \cdot R}$$

B (magnetic field); μ_0 , vacuum magnetic permeability; I , current intensity passing through the loop; R , loop radius.

The induced magnetic field tends to align with the magnetic field created by magnets placed near the loop. If the loop magnetic field induced is constantly changing, it keeps in movement.

Material

- Neodymium magnets (5-10 mm diameter aprox.)
- Copper wire
- Foundation for the copper loop (plastic cup, piece of wood, etc.)
- Battery or power supply

Experimental method
Roll copper wire around a marker for the loop. One of the loop ends has to be completely sanded, while only a half of the other should get sanded. This will allow to keep the loop movement. Another two pieces of copper wire must be sanded to be the loop support. One of the extremes will be rolled as a hook, and the others will be connected to a battery. This supports should be assembled to a foundation. Finally, two magnets must be positioned at the foundation bottom. Then, loop is placed over the "hooks" and battery terminals are connected. Propel the loop with your hands, and it will keep in movement.

Figure S4. Session S1. Scientific basis, materials and experimental method of: a) Potato battery experiment, b) Low-cost compass experiment, c) Oersted experience and d) Electromagnetic engine project.

a) **Experiment: Hand-made dynamo**

Scientific basis
The operation of a dynamo is based on electromagnetic induction. Concretely, Faraday's Law of induction, which states that the voltage or electromotive force (EMF), induced on a loop of wire is directly proportional to the magnetic flux (ϕ) variation which pass through the loop per unit of time (t). The mathematical expression that describes this phenomena is:

$$\epsilon = -\frac{d\phi}{dt}$$

This is essentially the basis of all the power plants electric generators.

Material

- 2 Neodymium magnets (5-10mm diameter approx.)
- Cooper wire
- Cardboard, plastic or PVC (for shaping the coil)
- LED
- Sand paper
- Wood or metal shaft
- Foam

Experimental method
Roll enameled cooper wire around of a cylindrical surface. This must be wide enough to introduce magnets inside. The coil may have 400 loops, approx.
The more loops it has, the higher current will be induced!
Two holes must be previously done aiming to place a metal or wood stick, acting as a shaft and supporting the "inductor" magnets. It is convenient that those magnet are well fixed to the shaft by means of a piece of wood or foam.
Finally, the enamel of the coil extremes must be removed. A LED will be connected to the coil terminals, thus the current induced could be directly visualized.

b) **Experiment: Paper propeller**

Scientific basis
Convection is one of the three mechanisms through which heat can be transferred. It requires a material media, and it is produced heat transfer between zones at different temperatures. Some examples are **boiling water** or **home heating**. The warmer fluid posses low density, thus it rises until getting colder and falling again. Newton's law of cooling mathematically describes such phenomena

$$\frac{dQ}{dT} = K \cdot (T_1 - T_2)$$

Q Heat
T Temperature
K Cooling parameter

Material

- Paper and propeller template
- Wood or metal stick
- 1 or 2 beads
- Glue or silicon
- Clay or plastic bottle (foundation)
- 4 candles
- Lighter or matches

Experimental method
Create the paper propeller itself, by means of a template. The center of the propeller must be correctly defined, other way it is not stable
Choose a stick for supporting the propeller. With the purpose of maintain the height of the propeller, it can be placed over a bead fixed to the stick.
Finally, the propeller should have an enough resistant foundation such as piece of clay or a half filled bottle with a hole on the cover. Fire the candles and the paper propeller will start to move due to the convection phenomena.

c) **Project: Wind propeller**

Scientific basis
The scientific basis is the same as the one seen at "Hand-made dynamo" experiment, since a dynamo is used for switching on the LED. Click [here](#) for returning back.
Within this project, the mechanical energy provided by the wind turns into electricity at the dynamo output.

Material

- Plastic spoons
- Soda covers or ice cream sticks and pen
- PVC or/and carboards or similar
- Silicon gun

Experimental method
Experimental method depends on the wind propeller design, as well as material proposed.
Generally, a wind propeller must count with blades, which can be crafted, for example, with plastic spoons or ice cream sticks.
A support for that blades and a shaft are also necessary. It can be build on cardoard, CD's, etc. Depending on the design, the support and the shaft may be the same piece.
The wind propeller can be crafted within a vertical or horizontal concept, like depicted in the images.

Figure S5. Session S2. Scientific basis, materials and experimental method of: a) Hand-made dynamo experiment, b) Paper propeller experiment and c) Wind propeller project.

a) **Experiment: Protoboard**

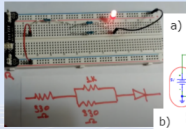
Scientific basis

The scientific basis concerning this experience is Ohm's law, which states that the relationship of electric potential difference (ΔV), intensity of current (I) and resistance (R) can be described as follows:

$$\Delta V = I \cdot R$$

Material

- Protoboard itself
- Wires
- Resistors (at least two: 330 Ω and 1k Ω)
- LED's (at least 1)
- 5 V Power supply



Experimental method

First, assemble circuit a), the resistors and the LED are in series. Take the multimeter and place the terminals in points A and B, respectively. If measure is negative, change terminals position. Take note of potential difference, electric current (ask the teacher or search for information about how to connect the multimeter), and electric resistance of the resistors and LED. Then, verify Ohm's law.

Assemble circuit b) and repeat the process with A-B and A'-B' points. Now resistors are in parallel and one resistor is in series with the LED. Which magnitudes have changed?

Scientific basis

The scientific basis is the same as the one seen at "Hand-made dynamo" experiment, since a dynamo is used for switching on the LED. Click [here](#) for returning back to the explanation.

Within this project, some energy transformations are involved, and they can be summarized as follows:

```

graph LR
    A[Potential energy  
(water dammed)] --> B[Kinetic energy  
(water falling, shaft moving)]
    B --> C[Electric energy  
(engine output)]
  
```

Material

- Plastic spoons or bottle covers and wood sticks
- CD's or plastic circles
- Pulley system
- Metal or wood stick for the shaft
- 12 V engine
- Tray to collect the water
- Silicon gun



Experimental method

Experimental method depends on the waterwheel design, as well as material proposed.

Basically, a waterwheel must count with blades, which can be crafted, for example, with plastic spoons or ice cream sticks. A support for that blades and a shaft are also necessary. It can be built with wood, CD's, etc. The shaft can be a metal or a wood stick.

Finally, the waterwheel should be connected to an engine through a pulley system or by directly linking the engine with the shaft. Remember to place the system into a tray and reuse the water.

Figure S6. Session S3. Scientific basis, materials and experimental method of: a) Protoboard experiment, b) Small scale hydroelectric system.

a) **Experiment: Magnifying glass**

Scientific basis
Convex lenses are used in glasses for farsighted people. They can converge a beam of parallel rays to a point called "focus" or "focal point", placed on the other side of the lens.
At this point, all the energy is concentrated, thus high temperatures are achieved when solar beams pass through the lens.

Material
- Black cardboard or paper painted with a black pen
- Magnifying glass
- Sunlight

Experimental method
For finding the focal point, the magnifying glass must be zoomed in and out until a small and intense point appears. It is recommended to point over a black paper or cardboard, which absorbs more radiation and reaches high temperatures quickly.
This experience should be performed by a teacher, or in a minutely controlled environment, since fire could appear and get out of control.

CAUTION
This experiment may imply FIRE.

b) **Experiment: Photovoltaic energy**

Scientific basis
When sunlight (electromagnetic radiation) hits the photovoltaic plate, electrons are pulled or emitted by the silicon plate. Then, the electrons are driven into a circuit for power supply. The work function, W , (minimum energy necessary for emitting electrons) can be written as follows:
$$W = h \cdot \nu_0$$

Where h is Planck constant and ν_0 is the minimum frequency needed to pull the electrons out of the plate.

Material
- Photovoltaic "Solar kit"
- Sunlight

Experimental method
Direct the "Solar kit" photovoltaic plate towards the Sun, and check how the engine starts to move.

c) **Experiment: Stirling engine**

Scientific basis
Ideal Stirling cycle is a thermodynamic cycle comprised of two isothermal (temperature remains constant) processes (compression and expansion) and an isochoric (constant volume) and isobaric (constant pressure) processes.
First, the piston is ideally compressed while the temperature remains constant. Then it is produced a pressure rise at constant volume. That pressure rise drives the expansion phase, where the piston goes back at constant temperature. Finally a pressure drop occurs, turning back to the first stage.
This process is the basis of some thermosolar systems, where there is a movement (a piston or a shaft rotation) which is transformed into electricity, and the heat source is the Sun.

Material
- Stirling engine
- Burner (heat source)

Experimental method
Fire the burner and give the first impulse to the piston. The engine will keep in movement.

d) **Project: Solar oven**

Scientific basis
Solar oven working can be explained through two physical phenomena:
- Laws of reflection: Second law states that the angle of reflection is equal to the angle of incidence.
- Greenhouse effect: Sunlight crosses plastic or glass heating the object inside the solar oven. However, the radiation reflected by the object is in the infrared bandwidth, thus the temperature of the inside air rises.

Material
- Shoe box (or similar)
- Aluminium foil
- Cling film
- Black cardboard
- Chocolate (or something similar that could get melted or cooked).

Experimental method
Crop a flap on a shoe box cover (this will serve as a reflector) and coat it with aluminium foil. Cover the hollow with cling film.
Finally, coat the inside of the box with aluminium foil and put a black cardboard on the base, so as to reach higher temperatures.
Put a piece of chocolate (for example) in the interior and direct the flap to the Sun, ensuring that radiation is reflected inside. After some minutes, the chocolate will be melted.

Figure S7. Session S4. Scientific basis, materials and experimental method of: a) Magnifying glass experiment, b) Photovoltaic energy experiment, c) Stirling engine experiment and d) Solar oven project.