

## **Adapting a Solar Photovoltaic Panel Experiment for Blind Students**

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### **Abstract**

Renewable energy is a trending topic due to its importance in today's society especially because of global warming. Because of its importance, this topic should be discussed at schools in an inclusive education environment. Experimental work is a very good activity to provide students effective conceptual discussions, but it is necessary to improve the teaching-learning process for an inclusive education paradigm. In this paper we propose a low-cost experimental activity using arduino that allows regular students and blind students to explore together and understand features and properties about solar energy and a photovoltaic panel, such as how the electric power generated by the photocell depends on the angle of incidence of solar light and the load resistance of the circuit.

Keywords: Inclusive education, photovoltaic panel, arduino, energy transfer, experimental activity for blind students

### **Introduction**

In 1994, in a meeting held in the city of Salamanca, Spain, representatives from more than 90 countries and 25 international organizations wrote a statement about the basic guidelines for the inclusion of persons with disabilities in regular educational systems, in a fair and egalitarian manner.

In this extensive document, known as the "Declaration of Salamanca", guidelines for political and educational elements are presented where the following points can be highlighted (UNESCO, 1994):

- The educational programs must take into account the wide diversity of students;
- Students with disabilities must be enrolled in the regular education system of every country;
- The technology should be used to improve the success rate in school curricula;

The movement behind this document gained strength and the access of students with disabilities to a better education became a reality within schools worldwide in recent years. In Portugal, for example, the number of students with Special Educational Needs (SEN), including those with some type of disability, has increased significantly in recent years and the projection is that in 2020, the educational system will exceed more than 100 thousand students in this condition (Figure 1). This reality requires that educational institutions,

regardless of their education level, seek for new ways to allow students with special needs to complete their education cycle in a more equitable manner.

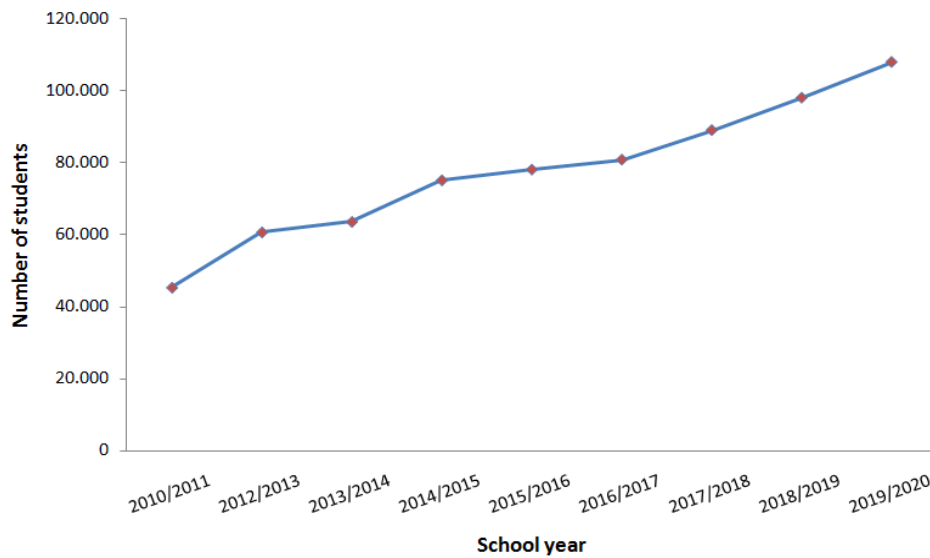


Figure 1 - Evolution of the number of students with SEN in Portuguese schools, and projection until 2020 (DGEEC, 2017).

The great challenge in some cases is that in some scientific areas like physics, chemistry and biology, due to the complexity of some subjects, it is fundamental to carry out experiments in order to perceive the phenomena in study and thus fully understand them. However, in most cases, the experimental activities are not adapted to guarantee the participation of the students with SEN, but when this is possible teachers frequently think on using methodologies only concerning to these students. This practice does not guarantee inclusion and induces teachers to make use of two different methodologies in the classroom: one for SEN students and another for the rest of the class. Within this perspective, seeking truly inclusive methodologies will allow all students and teachers to experience and understand the limitations and capacities of all students involved in an educational process.

We know that the process of developing experimental methodologies requires a sensitive and careful look, to prevent erroneous conceptions to be acquired by the students. The problem becomes more complex when looking for an activity that will be used by students with and without SEN. Thus, from this perspective a few steps should be taken:

- Evaluate the experiment to be adapted - Here the teacher must realize if the experiment to be used in the teaching practice can be adapted in a convenient way for SEN students, without compromising the learning of others;
- Propose alternative methods of presenting results - Despite the adaptation of some experiments, it is not always possible for students with SEN to carry out the quantitative steps directly. The ideal situation is that teachers can look for ways that guarantee them with a more complete learning;
- Perform the experiment - The next step is the assembly of the experiment. Teachers should seek, when possible, ways that can aggregate the use of information and communication technologies (ICT), thus allowing all students to be more concerned with the phenomena rather than the assembly of the experiment;

- Evaluate the quality of the results to be obtained - Before the experiment, it is fundamental that teachers think about the methodology for the proposed activity. Collaborative work between students with and without SEN should be considered, as well as whether the results will be perceived in the same way by all of them.

It is worth remembering that when there are students with different characteristics and learning difficulties in the same classroom, it may be difficult for the teacher to adapt the educational resources to suite all their particularities. However, if collaborative work and peer instruction practice is allowed and more forms of preparation of these resources are sought, the difficulties encountered during the teaching process will be minimized by the participation of a large number of students.

### **Justification and assembly procedures**

From an academic viewpoint, the activity chosen on this work is the experimental study of a photovoltaic panel. This activity has relevant features involved in the students' understanding about how this panel works, namely:

- \* Opening a discussion on the use of this technology for energy production;
- \* Showing that the electric current generated by the panel is dependent on the angle of light incidence;
- \* Discussing the reasons why the electrical energy generated by the panel also depends on the load resistance of the electric circuit.

In the original (non-inclusive) activity, taught in Portuguese secondary schools, students are encouraged to understand how independent variables of the system affect the energy generated by a photovoltaic cell.

To achieve this, students usually assemble the experimental setup of Figure 2 using the following circuit components: photovoltaic cell (SP), voltmeter (V), ammeter (A), rheostat (Rh), switch ( $S_1$ ), wires and an incandescent lamp as a light source (LS) to reproduce as close as possible the natural sunlight. The measurement of the power generated can be done mathematically, by calculating the product between the voltage (U) measured on voltmeter and the current intensity (I) measured on ammeter,

$$P = U I \quad (1)$$

while the value of the load resistance  $R$ , of the circuit, can be obtained by,

$$R = \frac{U}{I}. \quad (2)$$

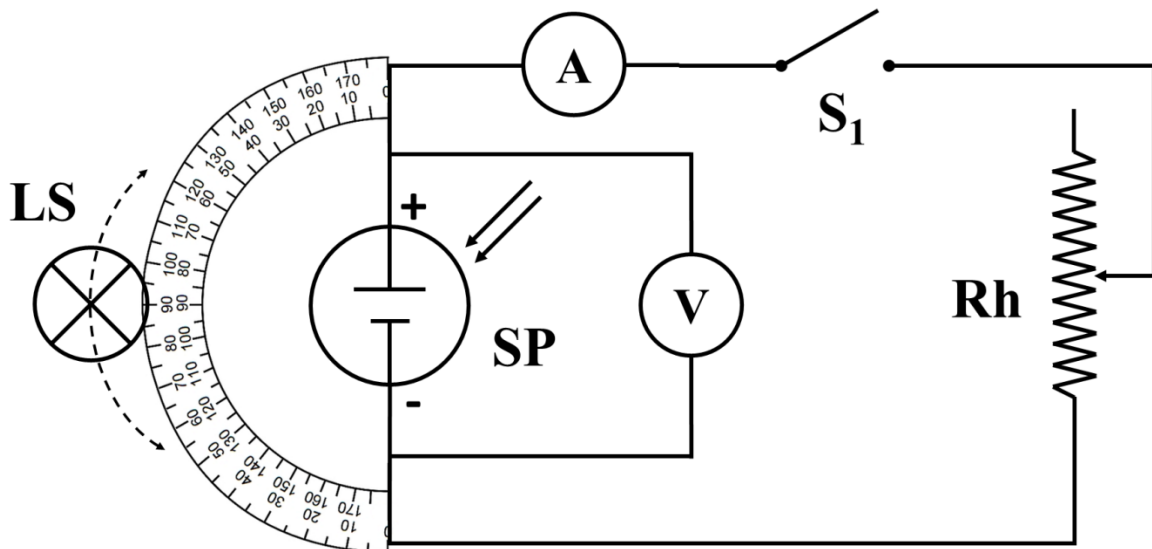


Figure 2 – Schematics of the usually assembled electrical circuit in high schools, where: LS – Light source; SP – Solar Panel or Photovoltaic cell; Rh – Rheostat; A – Ammeter; V – Voltmeter; S<sub>1</sub> – Switch 1

With the electrical circuit closed and the light source turned on, light energy is converted into electrical energy by the photovoltaic cell. This generated energy depends on the angle at which the light rays reach the surface of the photocell, as well as on the load resistance of the external circuit.

It is an experiment with visual characteristics that makes it impossible for blind students to participate autonomously in these conditions. Thus, blind students will find themselves frustrated to realize that this experiment has a weak meaning, if any, for them.

Thinking of an activity that can include blind students in the already mentioned discussion of the electric energy generation from solar energy, the following goals were established:

- Allow that the effect of the angle of incident light relatively to the solar panel can be perceived unequivocally by a larger number of students;
- Assure that a process similar to graphical construction can be done by blind students with objects/signals that allow a similar understanding of the physics involved in the experiment;
- Make data results available in digital format that can be used by all the students with access to digital text reading software.

The goal is to provide tools for blind students who, for practical reasons, develop the use the other senses (haptic perception, olfaction, taste, hearing) for the perception of the world that surrounds them, with an intensity greater than for those who do not have visual impairment (NUNES & LOMÔNACO, 2010). Therefore, the adaptation to be introduced in the experimental setup takes advantage on this, hence leading to qualitative and quantitative acquisitions:

- a) To obtain a qualitative measure of the electric power generated by the panel, we use an Arduino microprocessor to convert electric signal to sound whose frequency is proportional to the signal: the higher the pitch, the higher the power generated by the photovoltaic panel.

- b) The quantitative measure of the angle of incidence of light can be done by extending the protractor and writing the corresponding angles in Braille, allowing blind students to read the values (MEC, 1970).

To achieve this goal, we improved the experimental setup of Figure 2 by connecting an Arduino microcontroller board to the circuit to measure the voltage and current produced by the photovoltaic panel (which are printed on a separated window inside the Arduino IDE, called Serial Monitor), and a piezoelectric buzzer that generates different sound frequencies according with the generated power by the photocell (Figure 3 and Figure 4). This connection makes the buzzer produce lower frequency sounds for low generated power, and higher frequency sounds for high generated power, allowing blind students realize how the power generated by the photovoltaic cell changes according to different parameters. Moreover, a program that reads screens can be used and the blind students may not only hear the change in frequency, but also know the value that was measured.

The experiment was conducted with room light off, but still with ambient light from outside, since its amount was overwhelmed by the light source.

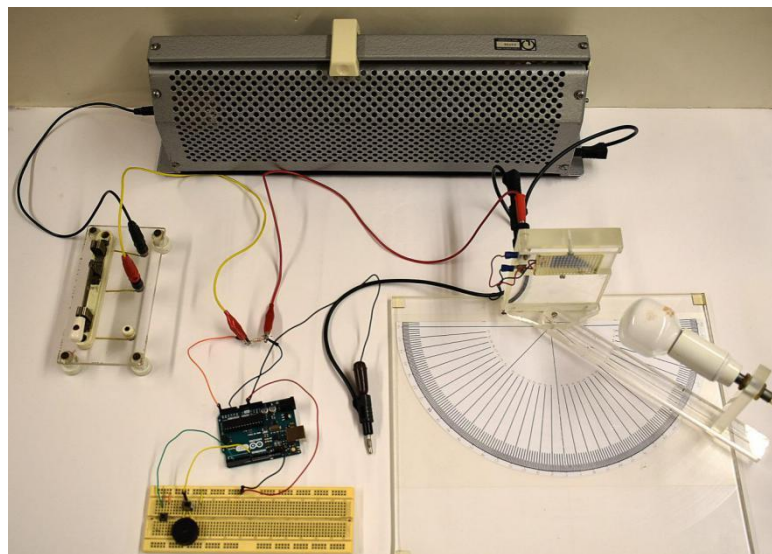


Figure 3 – Improved experimental setup.

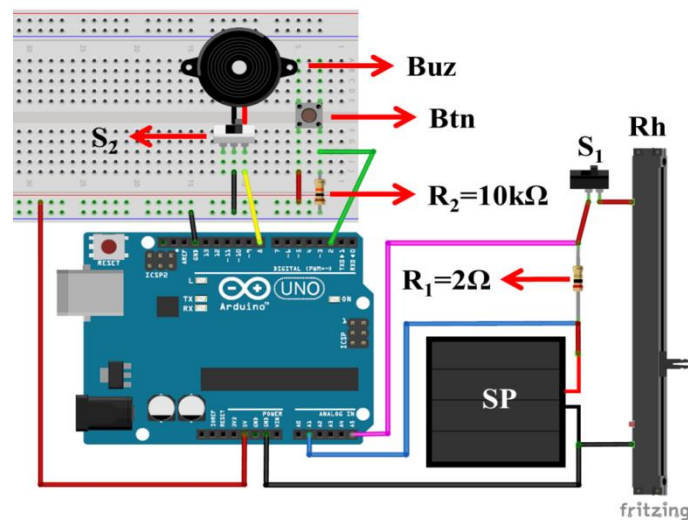


Figure 4 – Schematics of the improved experimental setup of figure 3 using Arduino, where: SP – Solar Panel or Photovoltaic cell; Rh – Rheostat; S<sub>1</sub> – Switch 1; S<sub>2</sub> – Switch 2; R<sub>1</sub> – Resistor 1; R<sub>2</sub> – Resistor 2; Buz – Piezoelectric buzzer; Btn – Button.

It is very important to notice that:

1. The first switch (S<sub>1</sub>) is used as a global switch to cut off the current in the circuit and the second switch (S<sub>2</sub>) is used to silence the buzzer, if needed.
2. The first resistor (R<sub>1</sub> = 2.0 Ω) is used to infer the current value in the circuit, allowing the removal of the ammeter. The second resistor (R<sub>2</sub> = 10.0 kΩ) is used to stabilize the signal in pin number 2 of Arduino.
3. Pressing the button (Btn) enables the simultaneous measurement of the voltage in the photovoltaic cell and the value of the electric current. The result is sent to the computer screen through a serial communication between Arduino and computer.
4. Measuring the electric potential difference (U) using Arduino is not difficult. It is possible to measure U generated by the photovoltaic cell and in the 2.0 Ω resistor using analog ports of Arduino. Since we know, by Ohm's Law that  $U=RI$ , this relation is used to infer the value of the electric current.

## Experimental Results

To make sure that the measured values with Arduino were consistent with the values of the original experiment, a new setup was built joining Arduino, the voltmeter (V) and the ammeter (A), so that they could perform measurements simultaneously (Figure 5).

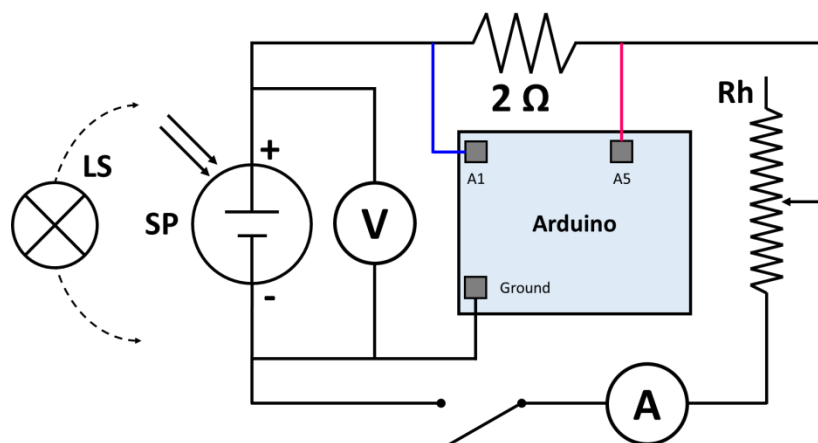


Figure 5 – Experimental setup schematics (except the breadboard) used to verify the accuracy of measured results. V and A represent the voltmeter and the ammeter, respectively.

With this new setup, we made the following experiments:

### Experiment 1: Measurement of the electric power generated as a function of the light incidence angle

In this first experiment, the voltage (U) and the current (I) generated by the panel for a particular angle of incidence of light, was measured by the multimeter and determined directly from the Arduino readings (Figure 6). The electric power,  $P = UI$ , was then calculated from the data, and converted by Arduino into a sound frequency emitted by the

buzzer (search for the file at: <https://youtu.be/qLSc65ohjA4> ). The code for Arduino is given in Appendix A.

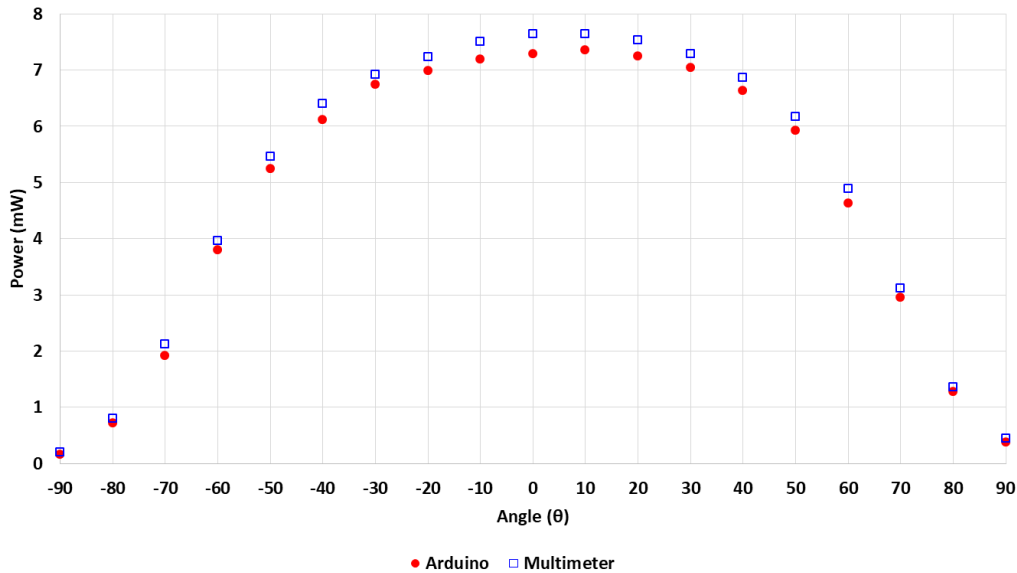


Figure 6 – Representation of the electric power generated by a photovoltaic panel as a function of the angle  $\theta$  of the incident light.

From Figure 6, it is possible to perceive curves with similar qualitative behavior, and quantitatively close values, thus indicating that the experimental setup is reliable for this measurement.

The slight difference between data in Figure 6 may be related to following factors:

- The protractor was not perfectly symmetrical to the photovoltaic cell location;
- The available photovoltaic cell is also not a perfect rectangle, but as shown in Figure 7, favoring one side of the light source than the other.

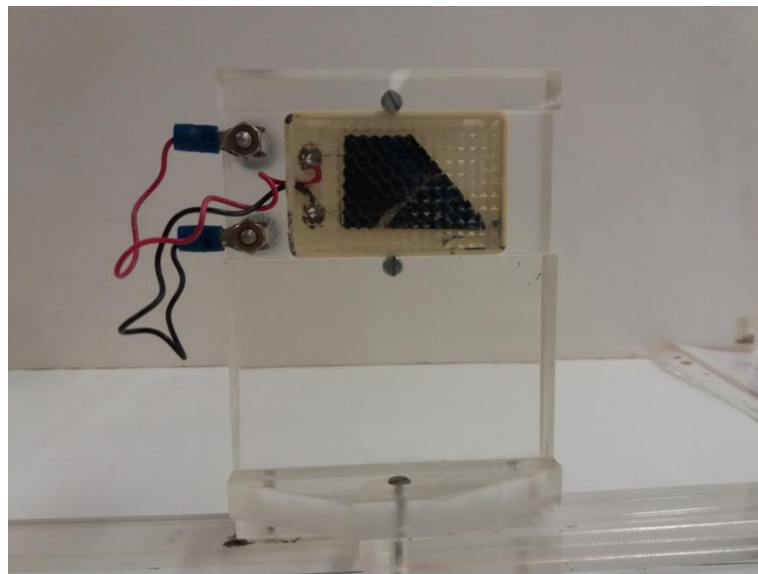


Figure 7 - Representative figure of our asymmetrical photovoltaic panel.

The experiment allows the students to realize that the power generated by the panel is dependent on the angle  $\theta$  of light incidence, and that the maximum electrical power corresponds to a higher pitch of the sound from the buzzer. This is always obtained for a light incidence perpendicular to the panel. Blind students can use touch or multiplane tool (Andrade & Silva, 2013; Costa, 2016) to quantitatively identify the angle. From pedagogical viewpoint this result can be useful for teachers to explain why in solar parks, the photovoltaic panels are rotated accordingly to solar time to enable a permanent normal light incidence, hence maximizing the power production of electric energy. In the northern hemisphere we find static solar cells on the roofs of residential and commercial buildings facing south, because in this hemisphere the apparent movement of the Sun in the sky along the day goes from east to west passing at the cardinal south point at solar noon, when the Sun is in its highest apparent position in the sky.

### Experiment 2: Measurement of the electric power generated as a function of the load resistance

In this second experiment the light source was kept at a fixed angle and the electric power (P) of the photovoltaic panel was determined while the load resistance (R) of the circuit was changed. Every time the load resistance is changed, students can gather the values of voltage generated by the photovoltaic cell and the current intensity that flows in the electric circuit, therefore computing the generated power. The change in the load resistance was done in small amounts in order to obtain enough data to identify the value where the generated power was maximum (Figure 8).

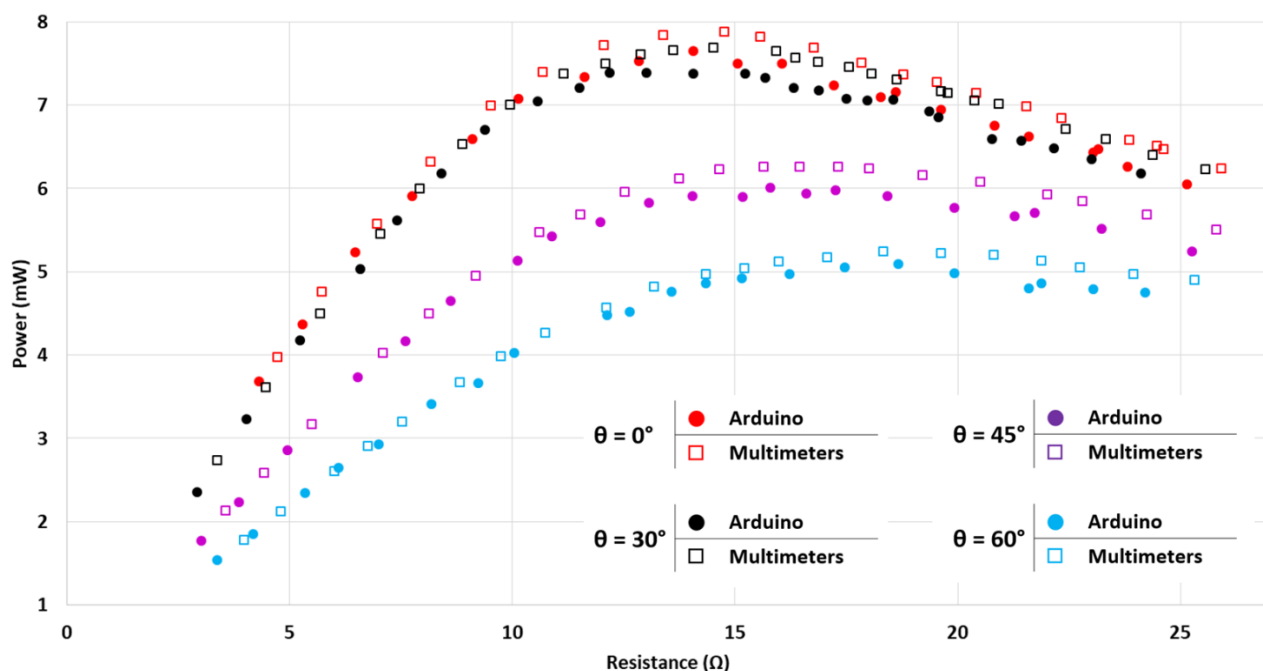


Figure 8 – Generated power in a Photovoltaic panel as a function of the load resistance, for different angles of light incidence.

With this adapted activity the frequency of the sound emitted by the buzzer changes while the load resistance in the circuit is altered, allowing blind students to realize that this change directly affects the behavior of the power generated in photovoltaic panel (search for the file at: [https://youtu.be/YOV5dTI\\_SJc](https://youtu.be/YOV5dTI_SJc) ).



An important aspect of this experiment is its counterintuitiveness, because there is apparently no reason to predict that the electric energy generated by the panel depends on the (passive) load resistance  $R$  of the electric circuit. But this happens! The typical  $P$  vs  $R$  curve of a photovoltaic panel shows that the power is maximum at a specific value of the load resistance within the electric circuit (Figure 8). The reason for this behaviour cannot be explained directly from this experiment, but Paul and Gadner (1998) explained that the maximum power transfer occurs when the load resistance equals the internal resistance of the panel, i.e.,  $R = r_i$ , an effect that is known as the Maximum Power Transfer Theorem, or Jacobi's law (Thompson, 2009, pp. 405).

Teachers can decide to deepen the discussion with students explaining that photovoltaic panels are built with semiconductors, and it is known that the electric resistance  $r_i$  of a semiconductor is dependent on temperature: the higher the temperature the lower the resistance. So, as the light exposure will produce visible changes in the temperature of the panel, it is expected that the maximal output power of the panel occurs for different load resistances (Sibai & Aramvo, 2014). Indeed, Figure 8 shows that when the light incidence is perpendicular to the panel ( $\theta = 0^\circ$ ), the temperature of the panel reaches its maximal and  $r_i$  is low; hence the maximal generated power occurs for a lower load resistance when compared to different angles of light incidence ( $\theta > 0^\circ$ ).

Blind students can perceive the decrease of the maximal output power of the panel from the sound frequency emitted by the buzzer and by listening the displayed data on the Serial Monitor that can be done by a reading screen program.

### **Conclusion and final considerations**

The adapted experiment here presented allows a larger number of students, including those with disabilities such as blindness, to make important conclusions about how photovoltaic panels work, namely:

1. For a fixed load resistance, the power supplied by the photovoltaic panel is maximal for perpendicular light incidence, decreasing in a non-linear way as the angle of light incidence changes.
2. For a fixed angle of light incidence, the power supplied by the photovoltaic panel is maximal for a specific load resistance, corresponding to the internal resistance of the photovoltaic panel.
3. The higher the temperature of the photovoltaic panel (light incidence closer to the perpendicular), the higher the output power and the lower the load resistance for optimal output.
4. The behaviour of photovoltaic panels under sunlight has important implications in the electrical conditions that can maximize the production of electric energy.

Finally, we consider that the search for a truly inclusive education (not only integrated education), which takes into account the participation of all students, need a new approach for experimental setups adapted to all students. That will enable the construction of a more balanced society in the future. Another point is that the heterogeneity existing in a classroom should not be seen as a problem to be overcome, but rather as an opportunity for all teachers to search for new ways of presenting contents and to become increasingly better professionals.

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## Appendix A

### Code

```
//----- define several variable that will be used along the code -----
float volt, amp, voltreal, ampreal;
float fall, realfall, current, pot, resistance;
int y, amount, sound;
int Button = 2; //defines the button connected to pin 2
Piezzo = 8; //defines the buzzer connected to pin 8
//-----

void setup() { // part of code executed only once
  Serial.begin(9600); // sets the data rate in bits per second (baud) for serial data transmission.
  pinMode(Button, INPUT); // set the pin number 2 as an INPUT pin
}
void loop() { //part of the code running permanently

  //----- General informations -----
  // An analog port in Arduino is a 1024 bit pin, which means the values come in a range of 0
  to 1023.
  // By simple rule, it is possible to convert this 0-1023 interval to a range of 0-5 volts value.
  // For the sake of comprehensibility I define an "Arduino unit" that will range between 0 and
  1203 and
  // can be converted to real units, like volt (in this case between 0 and 5 V) or ampere.

  //----- Informations on the variables -----
  // volt = potential difference (in "Arduino units", values between 0 a 1023) measured in the
  photocell
  // voltreal = conversion of the above measurement to actual unit in volt
  // amp = potential difference in the 2 Ohm resistor (will allow us calculate the current in the
  circuit)
  // ampreal = conversion of the above measurement to actual unit in volt
  // fall = measurement the voltage drop on the 2 Ohms resistor
  // realfall = conversion of the above measure to actual unit in volt
  // current = value of the current intensity in the circuit calculated by Ohm's Law (realfall /
  resistance)
  //-----

  volt = 0; // defines volt as zero
  amp = 0; // defines amp as zero

  amount = 250; // defines the number of times the followin loop will execute
  for (y = 1; y <= amount; y++) { // average of several measurements to minimize
  fluctuations
    volt = volt + analogRead(A1); // reads the ddp on analog pin A1
    delay(1);
    amp = amp + analogRead(A5); // reads the ddp on analog pin A5
    delay(1);
  }
}
```

```
//----- Part of the code devoted to transform "Arduino units" in other units -----  
  
volt = volt / amount; //average difference of potential in the source (Arduino units)  
voltreal = 1000 * 5 * volt / 1023; //conversion from Arduino units to volt  
  
amp = amp / amount; //average difference of potential in the 2 Ohm resistor (Arduino units)  
ampreal = 1000 * 5 * amp / 1023; //conversion from Arduino units to volt  
  
fall = volt - amp; //difference of potential in the 2 Ohm resistor (Arduino units)  
realfall = 1000 * 5 * fall / 1023; //conversion from Arduino units to volt  
  
//-----  
  
current = realfall / 2.0; // determines the intensity of electrical current in the circuit  
pot = voltreal * current / 1000; // Uses the relation  $P = U \times I$  to infer the power generated and  
presents the result in mW.  
resistance = voltreal / current; // Uses Ohm's Law to infer the total electrical circuit  
resistance  
  
sound = 50 + (pot*15+200); // defines a frequency by multiplying the power by a factor for  
a more distinguished sound  
// the mathematical expression for the sound value was chosen by trial and error to produce  
the best results  
tone(Piezzo, sound); // Command that makes the Piezzo buzzer produces the sound in the  
frequency calculated above  
  
//----- The code below will print the results -----  
//----- on the screen when the button is pressed -----  
  
if (digitalRead(Button) == HIGH) { // verify when the button is pressed  
  Serial.print("| V: ");  
  voltreal = voltreal / 1000;  
  Serial.print(voltreal, 3);  
  Serial.print(" V | ");  
  Serial.print(" I: ");  
  Serial.print(current, 1);  
  Serial.print(" mA | ");  
  Serial.print(" P: ");  
  Serial.print(pot, 1);  
  Serial.print(" mW | ");  
  Serial.print(" load resistance: ");  
  Serial.print(resistance, 1);  
  Serial.println(" Ohm | ");  
  delay(1);  
}  
//-----  
  delay(1);  
}
```