APPLICATIONS OF SIMULATED VIRTUAL EXPERIMENTS IN PHYSICS EDUCATION: ANALYSIS OF THERMOMECHANICAL AND THERMOELECTRIC EQUIVALENTS

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Luciano Soares Pedroso[1], Fabrício Pimenta Neto[2], Giovanni Armando da Costa[3], Renato Aparecido Teixeira[4].

ABSTRACT

The article explores the relevance of computer simulations in the teaching of Physics, with emphasis on Simulated Virtual Experiments (EVS), focusing especially on the Joule experiment on the Thermomechanical Equivalent. These EVS are based on real experimental data, making it an innovative and extremely effective tool in the educational context. By providing a practical and interactive interface, simulations allow students to explore and understand complex concepts in a more accessible and dynamic way. One of the main advantages of EVS is their proximity to conventional laboratory experiments, as they are developed based on data obtained from real experiments. This characteristic brings students closer to the authentic conditions of scientific research, which offers them a learning experience that is richer in context and faithful to reality. Thus, students can not only understand abstract theories, but also apply them in practical scenarios, promoting a deeper and more meaningful assimilation of physics concepts. In addition, EVS provide great flexibility for experimentation. Through variable adjustments and precise measurements, students can immediately observe the effects of their actions in the simulations, which fosters active and exploratory learning. This approach encourages the discovery of relationships between different physical variables and promotes the development of crucial skills such as problem-solving and critical thinking. In the context of the National Common Curriculum Base (BNCC-Brazil) for high school, the use of EVS also strengthens the dialogue between Physics and Digital Information and Communication Technologies (DICT). In this way, it prepares students to face the challenges of a world increasingly driven by technology, integrating scientific learning with the use of digital tools that are increasingly present in various areas of knowledge and the job market.

Keywords: Simulated Virtual Experiment, Experimentation, Experimental Practices, TDIC, Thermomechanical Equivalent, Thermoelectric Equivalent.

[1] Doctor in Science and Mathematics Teaching – MNPEF – PPGECMaT - Federal University of the Jequitinhonha and Mucuri Valleys - Diamantina-MG – Brazil
[2] Doctoral student in Education - National University of Rosario - Rosario - Argentina
[3] Master in Physics Teaching – MNPEF - Federal University of Alfenas - Alfenas-MG - Brazil
[4] Master's student in Science, Mathematics and Technology Teaching - PPGECMaT - Federal University of the Jequitinhonha and Mucuri Valleys - Diamantina-MG - Brazil

INTRODUCTION

Technologies are present in virtually every aspect of our lives, influencing the way we interact, work, and learn. In education, in particular, technological advancement has brought significant innovations every year, improving methods and tools that seek to facilitate and enrich the teaching-learning process. These innovations not only make learning more accessible and dynamic, but also offer new possibilities for developing essential skills in the contemporary world.

In the teaching of Science, and especially in the teaching of Physics, the impact of these technologies is profoundly remarkable. The use of technological resources, such as computer simulations, interactive digital platforms, and computer-assisted experiments, has revolutionized the way scientific concepts are presented and understood by students. These tools allow students to experience and explore phenomena that would otherwise be difficult or even impossible to observe in a traditional classroom environment, bringing them closer to more active learning and connected with the scientific and technological realities of today's world.

In this sense, by incorporating these innovations, the teaching of Physics not only keeps up with technological changes, but also transforms into a more interactive, engaging, and accessible field of study, expanding learning opportunities for students.

In another sense, it is noted that over the years the teaching of Physics has faced epistemological challenges (Moreira, 2021). Understanding physical phenomena often requires visualizing processes that are not directly observable to the naked eye. In this context, computer simulations emerge as a preeminent educational tool, allowing students to explore, interact and understand challenging concepts in a more concrete way. A notable example of this approach is the application of computer simulations in the teaching of James Prescott Joule's (1818-1889) experiment on the Thermomechanical Equivalent.

Joule's experiment[5], carried out in the nineteenth century, brought to light the interconversion between mechanical and thermal energy, playing a crucial role in the construction of the theory of conservation of energy. However, the experiment involves subtle interactions between different forms of energy, making its understanding a challenging task for students. This is where computer simulations come into play, offering a highly promising way to illustrate the principles underlying Joule's experiment.

By exploring the theory and results of the Joule experiment, this paper describes how computer simulations can be employed to enrich the teaching of the Thermomechanical Equivalent and the Thermoelectric Equivalent, making abstract

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[5] III. On the mechanical equivalent of heat (royalsocietypublishing.org)

concepts more accessible and tangible for students. In addition to providing a detailed overview of Joule's experiment and its results, we will examine the inherent benefits of using simulations in this educational context. Through virtual interactions with simulations, students have the opportunity to visualize the processes involved in the Joule experiment, adjust parameters, and observe the results immediately. However, it is important to recognize that despite their advantages, simulations also have their limitations, and we will discuss how to overcome these challenges.

The application of computer simulations in teaching the Thermomechanical Equivalent and later with the Thermoelectric Equivalent not only enhances the understanding of the physical concepts involved, but also provides an engaging and interactive learning experience. By empowering students to virtually explore a classic experiment, we are empowering the next generation of scientists and engineers to develop a deeper understanding of the energetic interactions that govern our world.

In the following sections, we will examine in detail the Simulated Virtual Experiments (EVS) - Thermomechanical Equivalent & Thermoelectric Equivalent - and how computer simulations with an experimental bias can be actively applied in the teaching of this fundamental concept of Physics, highlighting the educational benefits that this approach provides.

JOULE'S EXPERIMENT AND ITS CONTRIBUTIONS TO THE PRINCIPLE OF CONSERVATION OF ENERGY

In the nineteenth century, as the scientific understanding of energy evolved, a pioneering experiment by James Prescott Joule played a crucial role in shaping the principle of conservation of energy in physics. The experiment, known as the Thermomechanical Equivalent of Joule, remarkably demonstrated the interconversion between mechanical and thermal energy, laying the groundwork for the understanding that energy is neither created nor destroyed, but rather transformed from one form to another.

At the heart of Joule's experiment was the idea that mechanical work done on a system could be converted into heat. Joule conducted a series of experiments in which water in a container was stirred by paddles driven by a mechanical system. The friction between the blades and the water dissipated kinetic energy, resulting in an increase in the temperature of the water. By measuring, with good accuracy, the changes in temperature and the amount of water, Joule was able to measure the mechanical energy that had been converted into thermal energy.

The experiment performed by Joule was a pioneering contribution to the principle of conservation of energy (Hewitt, 2023, p. 289). Prior to this experiment, understanding of the relationship between different forms of energy was limited. Joule's work demonstrated in a tangible way that energy could be transformed from one form to another, but the total amount of energy would remain constant. This was a crucial step towards the formulation of the principle of conservation of energy, which states that the total energy in an isolated system remains constant over time.

With this experiment, Joule's discoveries had profound implications for physics and the understanding of the fundamental nature of energy. The experiment, according to Hewitt (2023, p. 314) demonstrated that, despite the various transformations that energy could go through, the total amount of energy in an isolated system remained unchanged. This revolutionary understanding paved the way for the development of fundamental theories such as the first law of thermodynamics, which formalizes the principle of conservation of energy.

> More important than being able to enunciate what energy is is to understand how it behaves – how it transforms. We can better understand the processes and transformations that occur in nature if we analyze them in terms of energy transformations from one form to another or transfers from one place to another. Energy is nature's way of playing the game. (Hewitt, 2023, p. 314)

Not only did the Joule experiment play a key role in building the theory of conservation of energy, but it also significantly influenced the way science is taught in our schools.

In the next section, we will explore how computer simulations, using EVS, can be employed to make the teaching of the Joule Thermomechanical Equivalent and, in addition the Thermoelectric Equivalent, more effective and engaging.

COMPUTER SIMULATIONS AS MODELS

According to Moreira (2021), one of the mistakes in the teaching of Physics is not giving importance to models and modeling.

> The so-called exact sciences, such as Physics, are not exact, they are approximate, because they depend on scientific models and these depend on the approximations made, on how the variables are controlled. (Moreira, 2021, p. 5)

In the epistemological view of Mario Bunge, cited by Brandão, Araujo and Veit (2011), all physical theory contains an idealized aspect of a piece of reality and this idealization is called a model. This epistemological view, according to Nascimento (2014) is classic and well accepted in the scientific context. According to the author, it is noted that scientific knowledge is built, scientific models are built, scientific theories are built from these models. All this construction begins with a conceptual model of a phenomenon of interest, of a necessary problem situation. This model can evolve theoretically and mathematically and arrive at a theory, whose acceptance (which is always provisional), refutation (which can be definitive) or revision (introduction of modifications to improve it) depends on the experimentation that is carried out to obtain new data.

Based on what has been said so far, the conceptual field of didactic-scientific modeling in Physics can also be understood as the set of activities in Physics Teaching that aim at the creation and/or exploration of didactic versions of scientific models built by physicists. Such activities can be synthesized in three classes of situations, which are capable of giving meaning to the concepts that one wants to introduce. They are: (a) computational modeling activities: involving theory and simulation; (b) modeling activities in teaching laboratories: involving theory and experiment; and (c) computational-experimental modeling activities: involving simulation and experiment about systems, processes and physical phenomena.

With the conceptual field of didactic-scientific modeling and the three classes of situations in mind, the research group of the Federal University of the Jequitinhonha and Mucuri Valleys (UFVJM) – Diamantina-MG campus developed the Simulated Virtual Experiments (EVS).

EVS are computer simulations produced from the use of the so-called Digital Information and Communication Technologies (DICT) that have contributed significantly to the teaching and learning process of high school students (Sampaio, 2016; Edwards; Silva, 2019; Rego; Peralta; Silva, 2018; Moura; Branches; Lavor, 2020), of the Superior (Hadad; Melo Junior; Silva, 2018; Hadad; Silva, 2021), including in Distance Learning (Alonso; Silva, 2018). For example, in the work of Pedroso and Da Costa (2023), some EVS were used in the teaching of Physics for Rural Education, involving concepts of Newtonian mechanics with an adequate methodological bias for the operationalization of the activities of probing, investigation, and construction of concepts. According to the authors, in the conditions in which the activities were carried out – remotely, it was perceived that the conceptual domain and the ability to apply or abstract the students' concepts in different situations do not coexist at the same cognitive level, but that they are complementary, because in view of the verification of the indices of the scores obtained in the two surveys carried out about the students' previous knowledge, Considering the didactic sequences implemented, they noticed a significant conceptual gain of the class as a whole when the focused aspect is the percentage of "correct answers" in the second survey in relation to the first survey.

PARTICULARITIES OF EVS IN RELATION TO A COMPUTER SIMULATION (SC)

For the elaboration of about 180 EVS, the *Easy Java Simulations* (EJS) software was used [6]in the compilation of *Java Script* (js) due to its numerous resources that allow the construction of simulations that approach a physical phenomenon, with a high degree of interactivity and the contribution of a library of files that make it possible to change the questions proposed to the students at each moment that they manipulate them.

Computer Simulations bring with them significant differences when compared to the act of experiencing a scientific phenomenon. According to Medeiros and Medeiros (2002, p. 5), if such a difference is not noticed or even alerted, the simulations can sometimes communicate conceptions of the phenomenon opposite to those that the teacher intended to convey with its use. Still, according to the authors:

> All animation, all simulation are based on a modeling of reality. If this modeling is not clear to teachers and students, if the limits of validity of the model are not made explicit, the potential damage that can be caused by such simulations is enormous. (Medeiros and Medeiros, 2022, p.6)

With this premise in mind, the EVS were built in the light of real experiments carried out in the Physics laboratory of UFVJM.

EVS differ from CS in that they were developed based on the results emerging from the experiments they demonstrate. Thus, EVS start from models based on real data collected in real situations from a laboratory, observing the ambient temperature, relative humidity data, local gravitational acceleration, latitude, longitude, mechanical and electrical resistances, friction, among others. With the data, the EVS simulate in a modeled way, still with some limitations, the experiments that are intended to be employed.

Today there are about 180 EVS that have an experimental aspect, that is, they do not use merely mathematical proposals or computational modeling.

The EVS were built so that students can seek their answers through the construction of graphs, tables and mathematical functions to prove their results. Also, due to the use of the EJS, it is possible to provide the student with 180 different variations of the data presented in each virtual experiment, that is, each time the student renders – opens – the EVS, he is faced with a different situation from the data to be analyzed to prove the concepts involved in the experiment.

In this way, the EVS are close to what the National Common Curricular Base (BNCC) of high school presents when it disseminates, in its competence No. 3, referring to

[6] Easy Java Simulations Wiki | Main / EJS Home Page (um.es) – acesso em 07 set. 2024.

the Natural Sciences, highlighting the necessary dialogue between this area and its technologies:

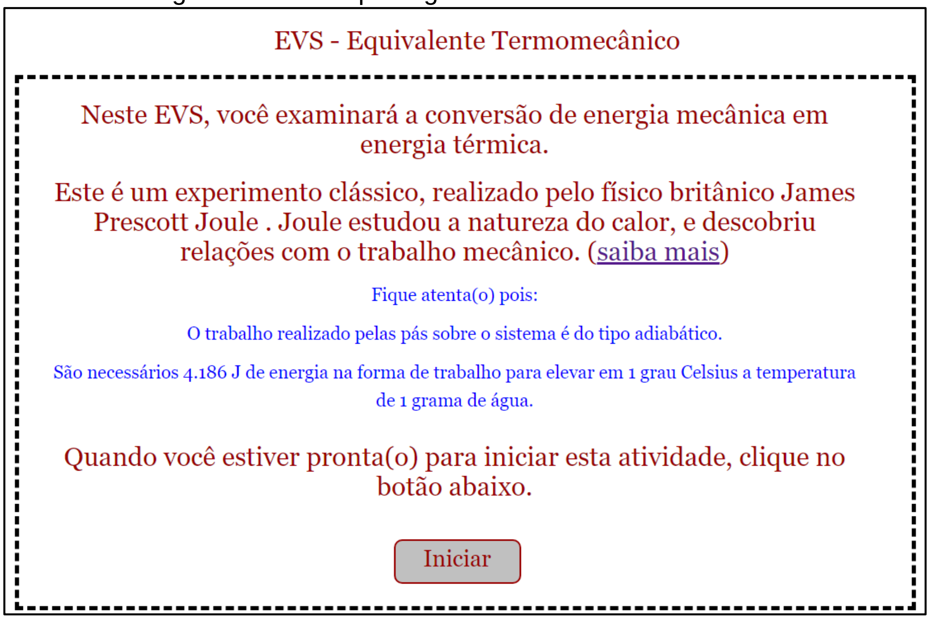
> Investigate problem-situations and evaluate applications of scientific and technological knowledge and their implications in the world, using procedures and languages specific to the Natural Sciences, to propose solutions that consider local, regional and/or global demands, and communicate their findings and conclusions to varied audiences, in different contexts and through different media and digital information and communication technologies (DICT). (BNCC, 2018, p. 553)

THE EVS THERMOMECHANICAL EQUILIBRIUM AND THERMOELECTRIC EQUILIBRIUM

THE THERMOMECHANICAL EVS

The EVS Thermomechanical was built using the experiment of the same name in the Physics laboratory of UFVJM. With the data collected during the handling of the experiment, and using the EJS software, the EVS was elaborated. The image below shows the opening/dialog screen when the student renders the EVS in their browser.

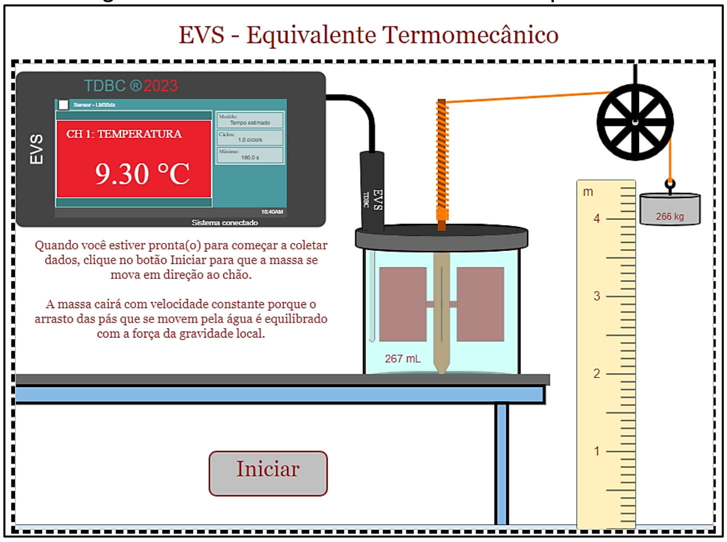
Figure 01: EVS Opening Screen - Thermomechanical



Source: Author's collection

Figure 01 characterizes the EVS dialog box where there is a small introduction to the subject treated, always followed by a link (learn more) where the student can learn a little more about the scientist and the story behind the proposed experiment. The importance of the history of Science is highlighted here because it offers a contextual and human perspective for the concepts and theories that students are learning. Some important points of this historical approach occur when it provides the opportunity to contextualize concepts, demonstrate the scientific method, the characteristics of scientific humanization, and demystify errors and scientific revolutions, the relationship between Science and Society, and makes interdisciplinary and transdisciplinary connections.

Figure 02: EVS – Thermomechanical Equivalent



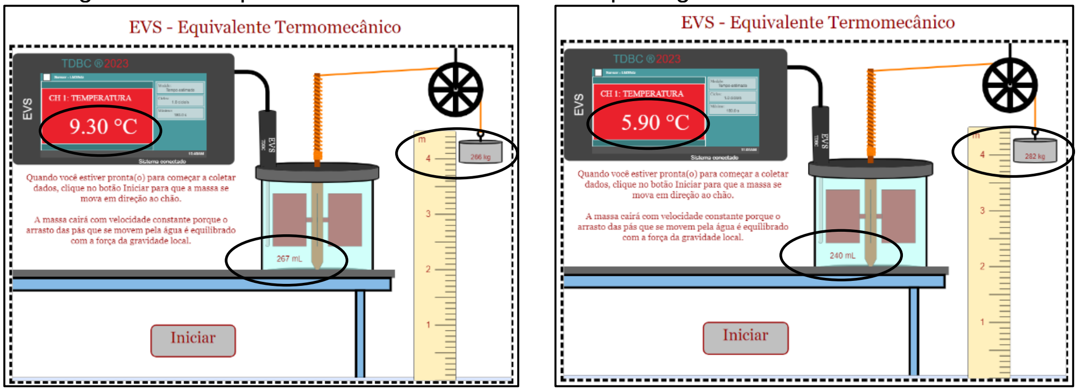
Source: Author's collection

In the image above, you can see the information necessary to carry out the experiment in an assertive way, where knowing the gravitational acceleration of the place where the experiment is carried out is summarily important.

When the student renders the EVS, the system provides some experimental data prefixed by the teacher-programmer. They are: traction mass – to modify it, the student just needs to click on it; mass of water in the calorimeter – to modify it, the student just needs to click on the calorimeter; Traction height in relation to the ground – to modify it, the student just needs to click on the pulley/pulley. All initial parameters (mass of the tractor, mass of water in the calorimeter, height of the tractor and initial temperature of the water will be modified every time (there are about 180 different settings) that the student renders the EVS in his browser, as seen in the highlights given in the image below. This type of approach makes learning individualized.

Self-paced learning is an educational approach that recognizes and tailors teaching to each student's unique needs, interests, and abilities. Rather than taking a one-size-fits-all approach in EVS, the self-paced learning in this experiment personalizes the teaching process to maximize each student's progress and success by enabling a variety of learning styles, autonomy, personalized feedback, continuous adaptation, skill development, motivation, and engagement.

Figure 03: Comparison between two different opening moments of the same EVS.



Source: Author's collection.

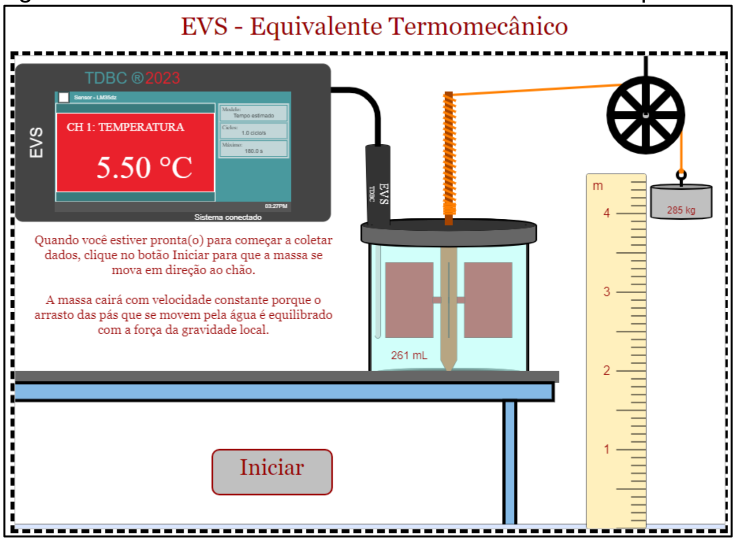
When the student clicks on the START button, the tractor begins its downward movement, converting the gravitational potential energy into thermal energy. Before starting the system, the student must write down the mass of the tractor, its height in relation to the ground, the volume of water in the calorimeter, the initial temperature of the water and research the value of the gravitational acceleration of the place where he is performing the experiment. The research of the gravitational acceleration value of the site is of fundamental importance for the experiment, since there is a conversion of Gravitational Potential Energy (E_{pg}) into Thermal Energy (ET). The EVS collects, in real time, the latitude and altitude of the place where the experiment is being carried out through the IP[7] (Internet Protocol) of the student's computer – when the user's computer is offline, the EVS uses the average value of the gravitational acceleration value of planet Earth: 9.82 m/s2 or 9.82 N/kg. It is important to highlight the importance of the experiment being as close as possible to a real experiment, giving the student the opportunity to experience concrete activities, even if it is virtual.

Below we will exemplify an activity that the teacher can carry out with his students.

First, the student must render the EVS in their browser. After reading the initial dialogue and knowing a little more about James Prescott Joule, he should open the[8] Weight Calculator app, provided by the teacher. This calculator must be opened on your Smartphone, independently of EVS. After obtaining the value of the gravitational acceleration of the site, the student must write down the data provided by the EVS. See the model below represented by figure 04:

[7] IP is one of the main protocols used in data communication on the Internet. It is responsible for identifying and addressing the devices connected on a network, allowing them to communicate with each other and share information.
[8] https://drive.google.com/file/d/1jXoITsluoqlnnUh1Rv-b8F0w9cPpj5GT/view?usp=sharing

Figure 04: EVS Initial Moment – Thermomechanical Equivalent



Source: Author's collection

Data collected by the student:

Local gravitational acceleration: let's assume that the experiment is performed at a latitude of -18º and at an altitude of 990m above sea level resulting in g = 9.78 m/s2

Traction mass: 285 kg

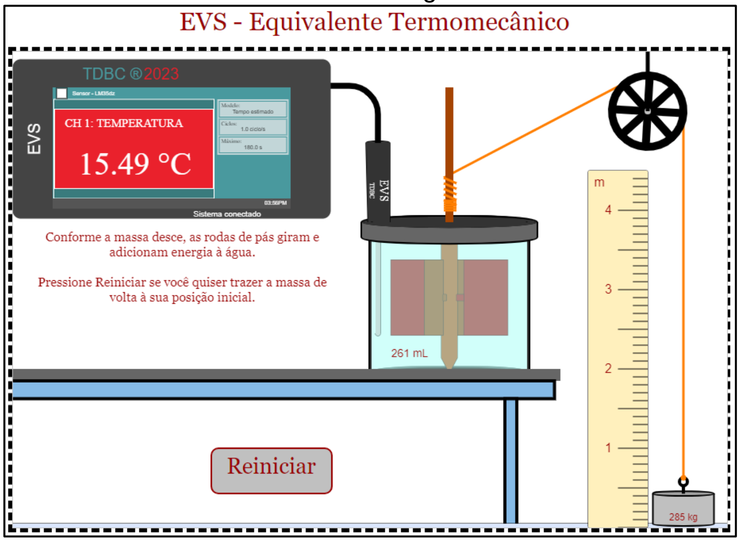
Volume of water in the calorimeter: 261 mL (here the student should remember that the density of water is around 1g/mL and therefore the mass of water in the calorimeter is 261 g.)

Initial water temperature: 5.50 ºC

At this point, the teacher can ask the student to find the value of the specific heat of fresh water in the international system of units. According to Halliday, Resnick and Walker (2016, p. 432), the specific heat of fresh water is worth 4,187 J/kg K or 1.0 cal/g ºC. This value is equivalent to saying that in order to increase a kilogram of fresh water by 1K or 1ºC, it is necessary to supply it with 4,187 Joules of energy.

After abandoning the tractor and waiting for it to arrive on the ground, the student will have the following screen:

Figure 05: Moment of arrival of the traction tractor at the ground with data to be collected by the student.



Source: Author's collection

Thus, the student's procedure for calculating the specific heat of fresh water will be:

$$Epg = E_T \quad (1)$$
$$m_{tracionador}.g.h = m_{água}.c.\Delta T \quad (2)$$
$$285.9,75.3,9 = 0,261.c.(15,49 - 5,50) \quad (3)$$
$$10.837,13 = c.2,61$$
$$c = \frac{10.837,13}{2,61} = 4.152,16\,J/kg\,K$$

The percentage error between the calculated value and the value found in the literature is less than 1%, as described below:

$$e_{\%} = \frac{|V_{lit.} - V_{cal.}|}{V_{lit.}}.100 \quad (4)$$

$$e_{\%} = \frac{|4.187 - 4.152,16|}{4.187}.100 = 0,83\%$$

The percentage error calculated above, also known as relative error, is a measure that quantifies the difference between an experimental value and a theoretical or expected value, expressed as a percentage of that theoretical value. It is a crucial tool in the analysis of experiments and measurements, as it helps to assess the precision and accuracy of the results obtained in relation to the theoretical or expected values. With an error of less than 1%, the EVS Thermomechanical Equivalent presents a good precision in the data provided, verifies the theory of conservation of energy, indicates that even in the case of an SC, the results have variation, giving the student and the teacher the opportunity to identify problems such as the precision of the equipment involved, calibration of the measurement instruments and, mainly, variation in experimental and environmental conditions. The percentage error also indicates that the EVS has points that should be improved, allowing us to investigate what were the reasons for occurring, such as heat dissipation to the environment in the vicinity of the calorimeter, behaving like real equipment.

If the teacher prefers, he can ask the student to find the mechanical power of the Thermomechanical Equivalent. To do this, the student must prepare his smartphone to time the traction drop time and thus obtain the mechanical power of the system.

By clicking on the START button on the EVS, the student simultaneously activates the timing button on his smartphone and collects the traction drop time. Suppose, for this experiment, the student finds 27.85 seconds for the tractor to touch the ground, so he can calculate the value of the mechanical power for his experiment:

$$P = \frac{\tau}{\Delta t} \quad (5)$$

Where:

P = mechanical power [W or J/s];

τ = mechanical work [J];

Δt = change in time [s].

For this calculation, the student can use the E_{pg} or the ET.

Take, in this example, ET:

$$Q = \tau = m.c.\Delta T \ (6)$$
$$Q = \tau = 0{,}261.4152{,}16.9{,}99 = 10.728{,}77\,J$$

Using (5), we fear:

$$P = \frac{10.728{,}77}{27{,}85} = 385{,}23\ W\ ou\ J/s$$

This result means that the experimental apparatus uses about 1/2 horsepower to convert the gravitational potential energy of the tractor into heating the fresh water in the calorimeter.

THE THERMOELECTRIC EVS

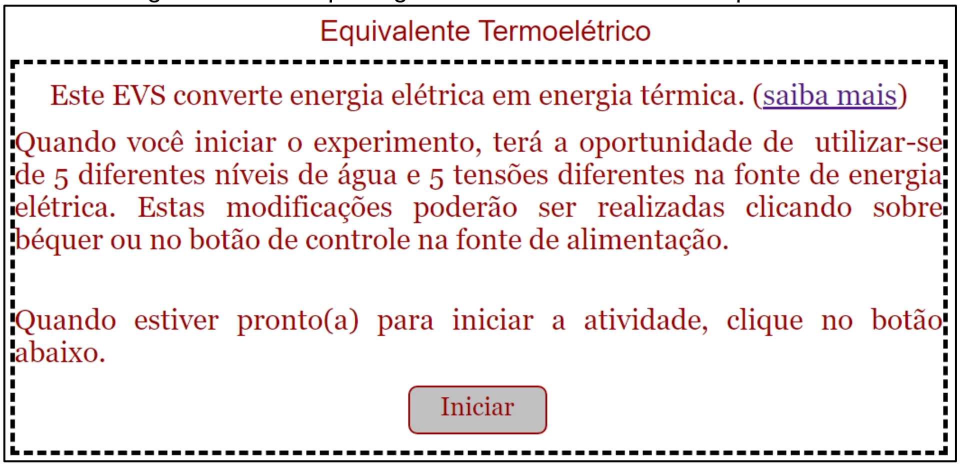
For the second EVS discussed in this article, the Thermoelectric Equivalent, we will explore the calorimeter used to demonstrate the conservation of energy in this experiment.

In order to know the actual calorimeter used in this EVS, it is necessary to conceptualize its thermal capacity. The heat capacity of an actual calorimeter is the amount of heat required to increase the temperature of the calorimeter by 1 degree Celsius. It is usually expressed in units of calories per degree Celsius (cal/°C) or Joules per degree Celsius (J/°C).

The heat capacity of a real calorimeter can be calculated by performing a simple experiment. The idea is to heat or cool the calorimeter with a known amount of heat and measure the temperature variation that occurs inside.

The image below depicts the open dialogue with the student when starting EVS.

Figure 06: EVS opening screen – Thermoelectric Equivalent



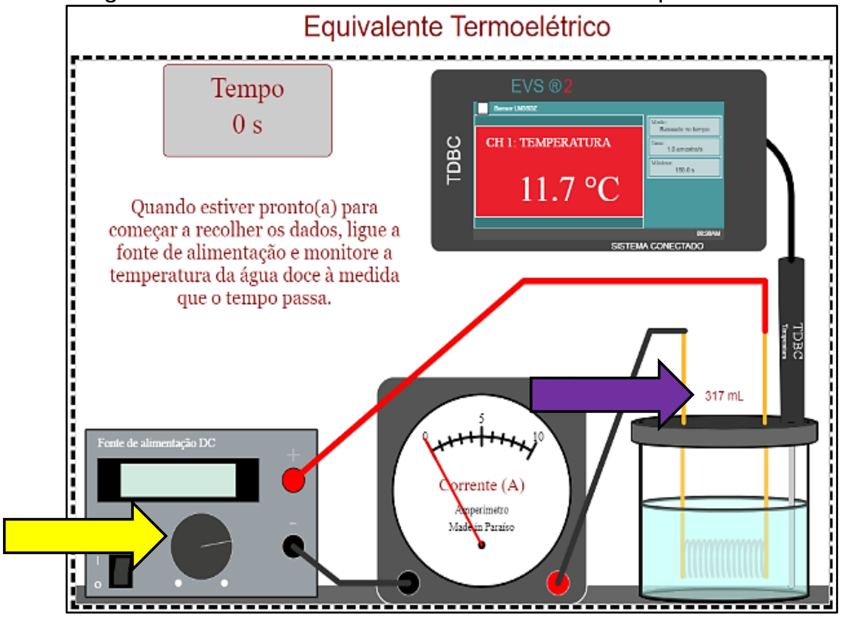
Source: Author's collection.

In the image above, the link (learn more) gives the student the opportunity to learn a little more about the discoveries of Thermodynamics throughout history, raising important points of Science such as evolution and discoveries; understanding the nature of Science; cultural and ethnic origins; interdisciplinary approach; among others, avoiding common misconceptions about scientific development.

After clicking on the START button, the student is redirected to the EVS Thermoelectric Equivalent screen, figure 07.

In the EVS, before supplying electrical energy to the resistor that is inside the real calorimeter, it has the opportunity to modify, according to some pre-established parameters – in particular, the value of the electrical voltage supplied by the power supply – by clicking on the button – and the amount of fresh water – by clicking on the calorimeter – that is in the container.

Figure 07: EVS initial screen – Thermoelectric Equivalent.



Source: Author's collection.

It is worth noting that when rendering the EVS, the student is faced with random values of the volume and initial temperature of fresh water in the calorimeter, leveraging individualized learning, a methodological bias adopted in all EVS developed by the UFVJM research group.

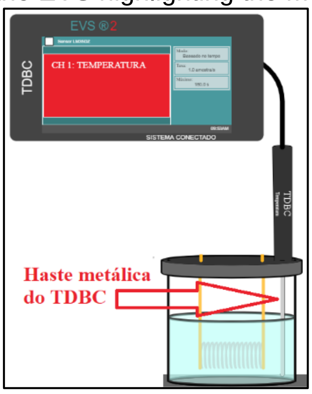
Another important observation in this EVS is the oscillation of the freshwater temperature value that is found in the calorimeter provided by the Low Cost Digital Thermometer (TDBC). This oscillation qualifies the experiment with data obtained in a real laboratory, because the ambient temperature causes the temperature oscillation inside the calorimeter, as it is a real calorimeter and has a thermal capacity that varies according to the initial temperature and volume occupied by the fresh water that is inside it. The article presented by Cosentino and Rios (2019), on page 8, brings this important observation when working with calorimetry experiments in Higher Education:

> This procedure, apparently safe, implies a series of risks of systematic errors that can compromise the quality of the experiment, resulting in values far from the expected for the specific heat of the test material, sometimes even obtaining negative values for this quantity, which results in absurd physical significance.

Another aspect pointed out by the authors is the use of hot water at the beginning of the experiment. According to data obtained by them, there is evaporation of part of the added water and the loss of energy is also due to convection, implying the maximum possible heat loss, significantly impacting the results obtained. In an attempt to minimize this energy dissipation by the calorimeter, which is real, it was decided to lower the initial temperature of the water in relation to the ambient temperature of the place where the experiment is carried out. To collect the value of the ambient temperature where the student performs the experiment, the EVS searches the Internet for data from the nearest weather station – according to the computer's IP – and, with this value, reduces the initial temperature of the water in the calorimeter. When the computer is offline, the ambient temperature is around 20 ºC.

There is still one more aspect to be observed when using this EVS or even performing this experiment in a laboratory: the thermalization of the system in the Joule Effect method. This method is a possible source of systematic error due to the fact that the water receives the heat dissipated by the resistance at the place where it is located, making the mixture heterogeneous in its temperature distribution. This fact may correspond to erroneous temperature readings by TDBC. An indication of this problem - when an electrical resistance is used at the bottom of the calorimeter - is the occurrence of jumps in the temperature reading, indicating moments of discontinuity in the tendency to increase it as a function of time. To minimize this effect, EVS adopted the TDBC with a metal rod, as shown in figure 08, capable of normalizing the temperature indication inside the calorimeter, relieving any type of water agitation and avoiding wetting a surface of the calorimeter much larger than that which would be touched by the volume of water at rest, thus avoiding further energy dissipation to the environment.

Figure 08: Cutout of the EVS highlighting the metal rod of the TDBC.



Source: Author's collection.

In order to find the value of the thermal capacity of the calorimeter adopted in this experiment, if the teacher chooses this approach, the following steps can be adopted.

It is known that the source of electrical energy of the experiment can be given by:

$$\Delta E = P.\Delta t \quad (7)$$

Where:

ΔE = energy supplied [J];

P = electrical potential of the equipment [W];

Δt = duration of the calorimeter being connected to the source of electrical energy [s].

It is possible to obtain the value of the electrical potential of the equipment using

$$P = u.i \quad (8)$$

Where:

u = electrical voltage supplied by the power supply of the experiment [V];

i = electric current supplied by the power supply [A].

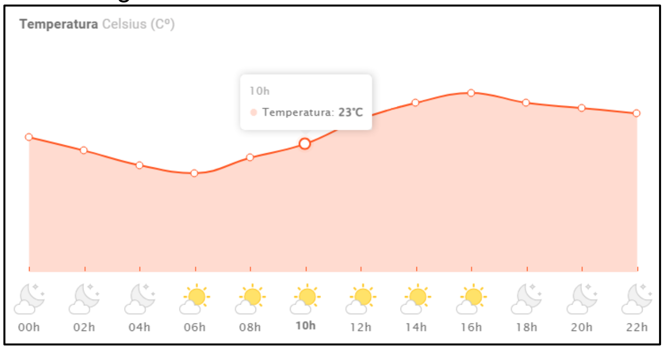
Thus, reorganizing (7) and (8) we have:

$$\Delta E = u.i.\Delta t \quad (9)$$

For this experiment, the following characteristics of the EVS are adopted (randomly):

Ambient temperature of the place where the experiment was carried out collected by the system (the data presented here were extracted from Clima Tempo on Aug. 23, 2024 at 10:08 am.

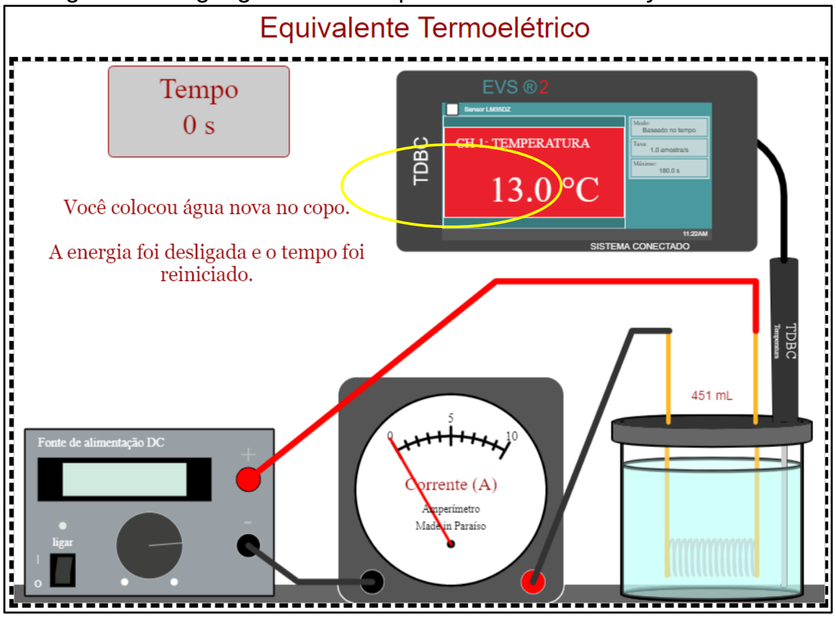
Figure 09: Climatic data at the EVS site.



Source: Weather Weather: Weather for today in São Sebastião do Paraíso - MG: Stay on top of the weather forecast (climatempo.com.br) Accessed on Aug. 23, 2024.

Figure 10 shows that the value of the initial freshwater temperature (13.0 ºC) inside the calorimeter is lower than the ambient temperature of the place where the experiment is carried out.

Figure 10: Highlight in the temperature measured by the TDBC.



Source: Author's collection.

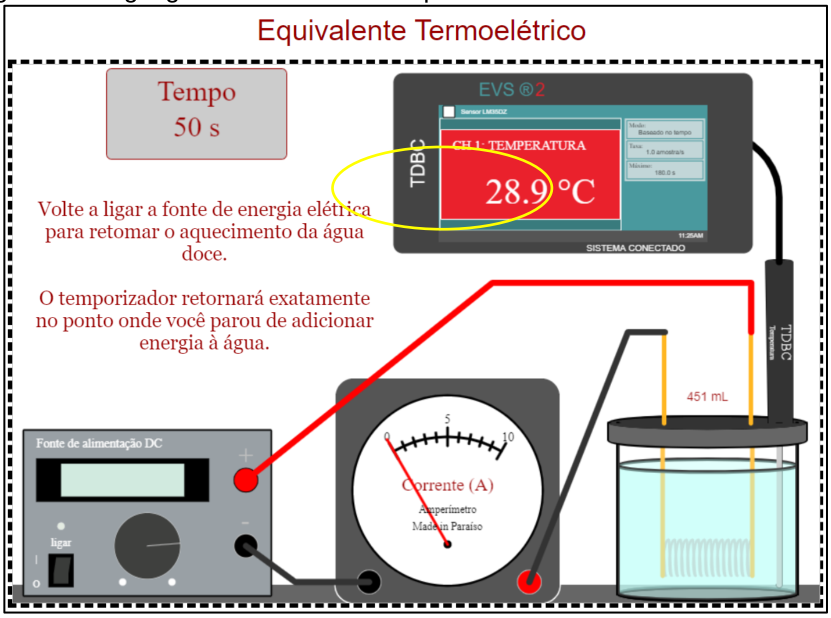
The initial data of the experiment, according to EVS, are:

a) volume of fresh water in the calorimeter: 461 mL;

b) initial freshwater temperature inside the calorimeter: 13.0 ºC.

After collecting the data, the student clicks on the selection button for the electrical voltage supplied by the source, according to his choice. Right after selecting the voltage, he must click on the 'on' button – at the bottom of the voltage source – to start supplying electricity to the resistance inside the calorimeter. Immediately when you click the 'on' button, the timer is triggered on the EVS, recording the time at which the electrical resistance supplies heat energy to the fresh water. It is noteworthy, here, that the transient power regime of the electric resistance should be disregarded. The student should write down the value of the electrical voltage and current supplied by the source to the electrical resistance. Note that the ammeter that indicates the value of the electric current is analog, allowing the student to use his skills in reading an instrument of this type. It is important to note that the scale of the analog ammeter changes when the student renders the EVS.

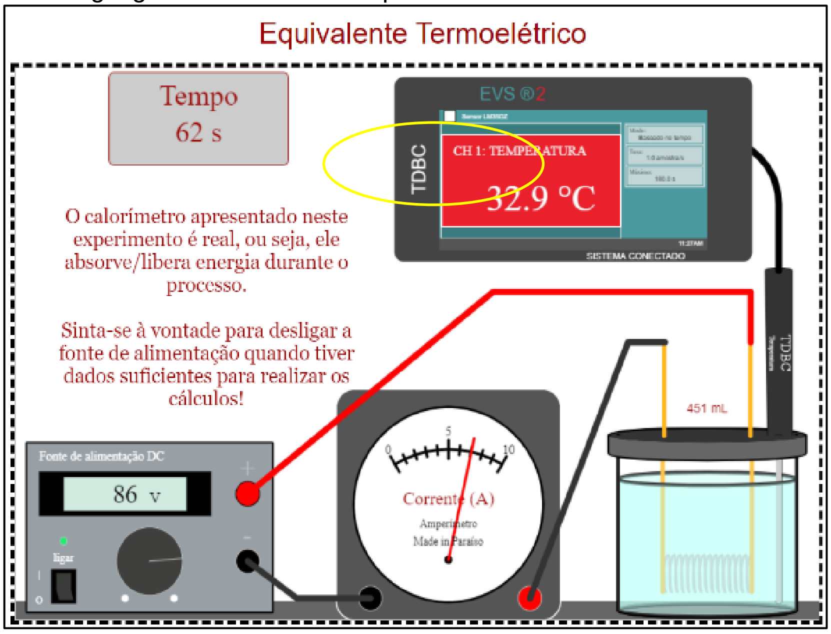
Figure 11: Highlight of fresh water temperature after 50 seconds of heating.



Source: Author's collection.

Suppose the student lets the power supply supply supply power to the fresh water for about 60 seconds and writes down the new water temperature value inside the calorimeter, as shown in figure 12.

Figure 12: Highlight of freshwater temperature after about 60 seconds of heating.



Source: Author's collection.

Some precautions must be taken before starting to take data, even if it is a virtual experiment. The first is that it is not certain that the calorimeter and fresh water are in thermal equilibrium. For this, as it is not possible and should not stir the water inside the calorimeter, the Ti of the calorimeter is adopted as the ambient temperature (as shown in figure 09 obtained from the Clima Tempo website). After this verification, the student can collect the data provided by EVS.

For this example, we have:

u = 86.0 V (incerteza: 1 V)

i = 7.2 A (uncertainty: 0.5 A)

$m_{\text{fresh water}}$ = 451 g (uncertainty: 1 g)

Initial T of fresh water: 13.0 °C (uncertainty: 0.1 °C)

Initial calorimeter t : 23 °C (uncertainty: 1 °C)

Final T of fresh water: 51.5 °C (uncertainty: 0.1 °C)

t = 120 s (uncertainty: 1 s) – it was decided to let the source supply energy to the fresh water for 2 minutes.

As it is an isolated environment, all energy consumed must be absorbed by the contents inside the calorimeter in the form of heat.

Like this

$$\Delta E = Q_{Total} \text{ or better } u.i.\Delta t = Q_T \ (10)$$

For this EVS, it should be remembered that the calorimeter is not ideal, so:

$$Q_T = Q_{água\ doce} + Q_{calorímetro}$$

Like this

$$Q_T = m_{água}.c.\Delta T + C_{calorímetro}.\Delta T \ (11)$$

Where c is the specific heat of the fresh water and C is the heat capacity of the calorimeter.

Reorganizing (10) and (11) we have:

$$u.i.\Delta t = m_{água}.c.\Delta T + C_{calorímetro}.\Delta T \ (12)$$

At this moment, it is possible to find the value of the calorimeter's thermal capacity with the data collected. However, it is necessary to measure the voltage, current, freshwater mass and initial and final temperature of the system several times and use descriptive statistics to obtain a significant result of the thermal capacity of the calorimeter, as pointed out by Cosentino and Rios (2019).

For this work, a variant to these statistical calculations is presented, maintaining the same methodological rigor.

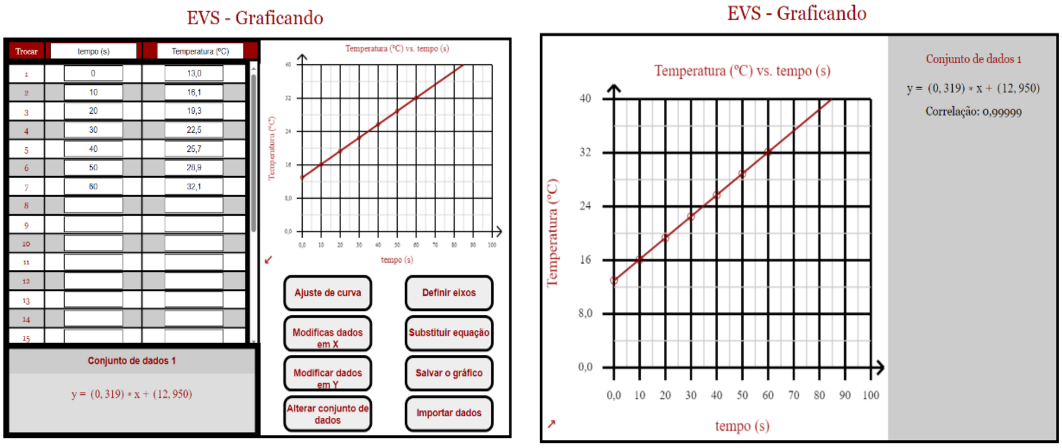
After the student chooses the voltage value that the source will supply to the system and clicks on 'Start', he waits for the start of heating the fresh water inside the calorimeter and monitors the time of this heating. It is assumed that the student chooses to monitor the heating time every 10s and write down the value of the freshwater temperature in each time interval, building a table with the data collected. After the composition of the table, he transfers this data to the Graph (figure 13) (created by the research group that presents this work for use in conjunction with the EVS) to build a graph with this collected data.

The Graphing is a graph plotter that allows the user to collect the data of an experiment, launch them in the columns that can be named, choose the best fit to the presented curve and ask the Grapher to plot the curve describing the equation that fits this curve and also present the correction of the data.

Some of the characteristics of Graficando are listed below and are in figure 13.

Graficando offers an intuitive, user-friendly, and easy-to-navigate interface, allowing students and teachers to explore and create graphs with ease, thus promoting advanced customization where users can customize chart details such as titles, axis labels, legends, and colors to make the visual presentation more accurate and engaging. Graficando provides data import allowing you to migrate your datasets from Excel spreadsheets – for example, in addition to having a curve fit including tools to fine-tune the curves to the data, allowing students to explore concepts such as linear and nonlinear regression, as well as analyze the quality of the adjustments. In addition, Graficando offers built-in simulation capabilities, allowing students to visualize how different parameters affect graphs and better understand the underlying scientific relationships. It is also possible for users to analyze specific points on the graphs, obtaining detailed information about the coordinates and relating these points to physical concepts. A highlight of Graficando is the possibility of exporting and sharing, allowing you to export graphics in various formats, such as images or documents, making it easy to share with colleagues or include them in presentations, becoming cross-platform when used on various devices and operating systems, providing flexibility to users to access and work on graphics anywhere. It should be noted that Graficando is constantly updated based on student *feedback*.

Figure 13: On (a) Graphing screen with data collected by the student. In (b) screen of the magnification of the graph generated by the data.



(a) (b)

Source: Author's collection.

Resuming the analysis of the data collected by the student, it is noted that the real situation is described by the expression

$$Q_{\text{água doce}} + Q_{\text{calorimeter}} + Q^*_{\text{ambient}} = 0$$

* According to Cosentino and Rios (2019, p. 3), the amount of heat provided by the environment can be disregarded.

Considering the situation presented so far, the following expression can be found for temperature as a function of the time elapsed, according to Cosentino and Rios (2019, p. 2):

$$T(t) = T_i + \left(\frac{u.i}{C_s}\right).t \quad (13)$$

Where the product u.i is the power dissipated by the resistor immersed in fresh water via the Joule effect; C_s is the total heat capacity of the set; t is the elapsed time (considering the initial instant at zero) and T_i is the initial temperature of the fresh water.

With the data collected by the student and the graph generated in the Graph, it is possible to calculate the thermal capacity of the system (C_{system}), understood here as being the result of the sum of: (water + resistor + TDBC rod + calorimeter).

By disregarding the thermal capacity of the resistor and the TDBC rod, we can find the thermal capacity of the calorimeter, since we know the mass and the specific heat of the fresh water that was inserted inside the calorimeter.

Thus, we have:

$$C_{sistema} = C_{água\ doce} + C_{calorímetro}$$

$$C_{sistema} = c.m_{água\ doce} + C_{calorímetro} \quad (14)$$

Using the equation presented by the Grapher in figure 13-b and relating it to (13), we find:

$$T(t) = T_i + \left(\frac{u.i}{C_s}\right).t$$

$y = 0{,}319x + 12{,}95$ or $T(t) = 12{,}95 + 0{,}319.t$

Where y corresponds to the temperature at the end of the process as a function of time and x corresponds to the time of data collection, arriving at the following representation:

$$\frac{u.i}{C_{sistema}} = 0{,}319$$

Knowing the values of the electric voltage u = 86 V and the electric current i = 7.2 A provided by the source, the C system is obtained.

$$\frac{86{,}0.7{,}2}{C_{sistema}} = 0{,}319$$

Csistema = 1941.1 J/ºC

Now, using (14) it is possible to verify the value of the thermal capacity of the EVS calorimeter, verifying what was stated throughout this work "the EVS calorimeter is not ideal":

1941,1 = 0,451*4187 + $C_{calorímetro}$
Calorimeter = 1941.1-1888.4 = 52.7 J/ºC

The value found above expresses the ease of temperature increase for a given amount of heat supplied to the system. In the special case dealt with in this article, the result means that in order to increase the temperature of the calorimeter by 1 °C or 1 K, it is necessary to supply or withdraw an amount of thermal energy of 52.7 J.

This value portrays an important characteristic of the calorimeter, as it affects its sensitivity and accuracy in determining the temperature changes that occur during chemical reactions or physical processes. The higher the heat capacity of the calorimeter, the more heat energy is required to cause a noticeable change in temperature recorded by the thermometer in the system.

Another concept that can be employed with the use of Thermoelectric EVS is to find the amount of heat that the calorimeter absorbs or supplies to the system. If the teacher wants his students to find the amount of heat (absorbed/ceded) by the calorimeter to fresh water at the beginning of the experiment carried out with the help of this EVS, he uses:

$$Q_{calorímetro} = C_{calorímetro}.\Delta T \quad (15)$$

$$Q_{calorímetro} = 52,7.(23,0 - 13,0) = 527,0 \text{ J}$$

which corresponds to 126.1 calories transferred from the calorimeter to fresh water because the temperature of the environment is higher than the initial temperature of the water inside the real calorimeter, corroborating Cosentino and Rios (2019, p. 10) when they state that

> "One of the reasons given for this fact is the issue that the exchange of heat with the environment can be significant..."

FINAL CONSIDERATIONS

This paper explored the application of computer simulations, specifically the Simulated Virtual Experiments (EVS) of Thermomechanical Equivalent and Thermoelectric Equivalent, in the teaching of Physics.

By facing many epistemological challenges, especially when it comes to abstract and complex concepts such as the Thermomechanical Equivalent, this article brought to light James Prescott Joule's experiment. By describing the experiment and characterizing its fundamental performance in the construction of the theory of conservation of energy, its understanding becomes challenging for students due to the subtle interactions between different forms of energy.

These interactions can be enhanced by computer simulations as they emerge as appropriate educational tools to make these concepts more accessible and tangible for students. They offer the opportunity to virtually explore a classic experiment, adjust parameters, and observe immediate results. However, it is essential to recognize that simulations have their limitations and challenges.

In addition, the article highlights the importance of models and modeling in the teaching of Physics, recognizing that the exact sciences are approximate and depend on scientific models. It is with this strand that EVS were developed, based on real data from experiments and offering an individualized learning approach, allowing students to explore a variety of situations.

This article thoroughly explored the potential of two Simulated Virtual Experiments (EVS) in Physics education, with an emphasis on calorimetry and energy conservation, presenting an innovative approach that can revolutionize the way students learn complex physics concepts by enhancing the personalization of learning when they offer a highly personalized learning environment.

By presenting random data and allowing students to experiment with different scenarios, they empower them to explore the nuances of physical concepts. This is particularly valuable as it recognizes that each student has unique learning styles.

By enabling realism and coherence with the real world, the EVS discussed in this article enhance elements such as temperature fluctuations due to the environment, systematic errors, and even the influence of water evaporation, providing students with an authentic experience, allowing them to better understand how these factors affect real experiments.

By handling the EVS and having access to real-time data such as ambient temperature information, students realize that this is a powerful aspect as it not only increases the accuracy of the results, but also demonstrates how physics is intrinsically linked to the environment around us.

By exploring the data and analyzing the results found throughout the experiments, the EVS presented here allow the stimulus to active exploration and the collection of evidence, enabling students to monitor water temperature at defined intervals, create graphs and analyze trends. This fosters a deeper understanding of physical concepts and data analysis skills.

The inclusion of tools such as "Graphing" further expands the capabilities of EVS. Students can adjust curves to the data collected, explore concepts of linear and nonlinear regression, and analyze the quality of these adjustments. These skills are transferable and useful in many fields beyond Physics.

EVS allows students to export results and easily share them with classmates and teachers. This functionality promotes collaboration and communication of scientific discoveries, encouraging a more interactive approach to learning, enabling them to delve into complex physics concepts in a more accessible way, exploring advanced and challenging topics with the guidance of teachers, providing a more solid understanding of the fundamentals of physics.

EVS can easily be used as platforms for physics research projects. Researchers, students, and teachers can conduct virtual experiments to collect data, analyze results, and develop new insights in specific areas of physics, as they allow teachers and researchers in the field to create simulations of complex physical phenomena that would be difficult to perform in real laboratories, further expanding the scope of the experiments they can perform.

Another point to be highlighted is the possibility of customizing experiments where teachers can adapt the EVS to meet the specific needs of their class, customizing the experiments according to the students' skill level, making learning more meaningful.

It is noted, as it is a DICT tool, that EVS are ideal for hybrid and remote teaching because they can be accessed from anywhere (*online* or *offline*), allowing students and teachers to continue learning, even when they are not physically present at school, in addition to enriching interdisciplinary collaboration where Physics concepts are applied to other curricular units, such as Chemistry, Biology, Engineering, and more, promoting a more holistic understanding of science.

The ability to update EVS based on student *feedback* is indicative of the UFVJM research group's commitment to the continuous improvement of its Simulated Virtual Experiments, ensuring that these tools are always aligned with ever-evolving educational needs.

In this sense, and as observed in this article, Simulated Virtual Experiments offer a new paradigm in physics teaching by making complex physical principles more accessible and engaging, promoting in-depth understanding and critical analysis skills. As such, EVS has the potential to revolutionize the way Physics is taught and learned, empowering teachers, researchers in the field, and especially students to explore the scientific world in an interactive and meaningful way.

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