

## Virtual Simulations of Electromagnetism in Science Teaching to favor the Scientific Literacy process<sup>+</sup>\*

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### Abstract

*Didactic changes in the teaching and learning process of Science are directly connected to the historical context and the development of the Science and Technology. This work deals with the contributions of virtual simulators and Digital Information and Communication Technologies to the teaching and learning process of Physics with the theme "Energy and Electromagnetism" in the Middle School. The objective of this paper is to verify and report how activities with an investigative approach, using the online simulations of the PhET project, can favor the process of Scientific Literacy in 8th grade students of the Middle School. This is a qualitative research carried out with 27 students from 13 up to 14 years old of a private school in the interior of the São Paulo state. To analyze the Scientific Literacy process, during the application of the didactic sequence, the indicators suggested by Sasseron were used. The results obtained evidenced the presence of the indicators of organization and the classification of information, logical and proportional reasoning, survey and hypothesis test, justification, prediction and explanation. The presence of the indicators has shown that investigative activities, using virtual simulators, favors the Scientific Literacy process in the students, since it promoted the learning of scientific procedures developing the concepts of the electromagnetism through research and experimentation.*

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## **I. Introduction**

Science teaching in schools goes through constant transformations. These didactic changes in the pedagogical process are directly linked to the historical context and, mainly, to the advancement of Science and Technology, which are increasingly present in the daily lives of students (CHAGAS; SOVIERZOSKI, 2014; GUILHERME; CHERON, 2019; ZÔMPERO; LABURÚ, 2011).

Access to information and social interactions are increasingly and mediated by Digital Information and Communication Technologies (DICT) (KENSKI, 2012). Therefore, the teaching and learning process must include didactic practices capable of exploring these new forms of interaction, communication, production, and dissemination of knowledge (KENSKI, 2012; LÉVY 2000).

Currently, Science Teaching must commit to the Scientific Literacy of students, making them capable of understanding and transforming nature and society through scientific and technological knowledge (BRASIL, 2018; SASSERON, 2015). The study by Brito and Fireman (2016) points out that pedagogical practices based on research-based teaching when developed in Middle School, can positively favor the process of Scientific Literacy.

In this context, the simulations reported in virtual laboratories can be considered tools capable of providing experimental activities to students, especially in places where real experimentation is not possible or viable. For Paula (2017), this tool, when used with an investigative approach, favors students' protagonism during the teaching and learning process. However, it is necessary that teachers and "*researchers are encouraged to study both the limits and potential of these resources in teaching and learning environments guided by an investigative approach*" (PAULA, 2017, p. 99).

The pandemic caused by COVID-19 led to major changes in the teaching and learning process, with Basic Education schools having to adopt remote teaching and later the rotation system, interspersing groups of students present in the classroom and others accompanying them from online form. These conditions made real experimental activities unreliable, especially those that could put students' safety at risk. Given the above, DICT have strengthened themselves as facilitating tools for conducting experiments and investigations.

Therefore, the current work deals with using interactive online simulations of the *PhET*<sup>2</sup> project for teaching physics with the theme "Energy and Electromagnetism", intending to promote the process of Scientific Literacy in students in the 8<sup>th</sup> year of Middle School. The objective of this article is to verify and report, through the indicators proposed by Sasseron

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<sup>2</sup> Laboratório de Eletromagnetismo de Faraday (2.07.01). Disponível em: [https://phet.colorado.edu/sims/cheerpj/faraday/latest/faraday.html?simulation=faraday&locale=pt\\_BR](https://phet.colorado.edu/sims/cheerpj/faraday/latest/faraday.html?simulation=faraday&locale=pt_BR). Acesso em 03 out. 2022.

(2008), the contributions of online simulations with an investigative approach to Scientific Literacy in the scenario imposed by COVID-19. It is worth highlighting that verification, through indicators, occurred throughout the research process and the main results are reported in this document.

## II. Scientific Literacy and Inquiry-Based Teaching

For Chassot (2003), Science can be considered a language. Thus, a scientifically literate being must be able to read nature and interpret it. From this perspective, Scientific Literacy is related to the individual's ability to read, interpret, and position themselves based on scientific knowledge (LORENZETTI; DELIZOICOV, 2001).

It is through Scientific Literacy that formal education prepares students to be agents of transformation in society, as scientific knowledge when understood, is capable of contributing to more assertive decision-making, especially in the increasingly dynamic environment in which they are inserted (BRASIL, 2018; LORENZETTI; DELIZOICOV, 2001).

For Sasseron (2015), scientific knowledge is not something finalized or an absolute truth; it is constantly changing and follows scientific advancement. Therefore, the Scientific Literacy process must also always be under construction and analysis of new situations during the teaching and learning process. The new situations, generated by this dynamic and the emergence of new knowledge, favor the *“construction of understanding, decision-making and positions that highlight the relationships between sciences, society and different areas of knowledge”* (SASSERON, 2015, p.56).

From this perspective, checking whether the Scientific Literacy process is being favored during the pedagogical practices carried out in the classroom is not a simple task. To assist teachers in this task, Sasseron (2008) proposed indicators to identify and evaluate the Scientific Literacy process, as shown in Chart 1.

Chart 1 – Description of Scientific Literacy indicators proposed by Sasseron (2008).

Scientific Literacy indicators		Description indicators by Sasseron (2008)
Group 1	Seriation of Information	It is linked to the establishment of bases for investigative action. It does not necessarily provide for an order that must be established for the information: it can be a list or a list of the data worked on or with which one will work.
	Organization of Information	It arises when trying to prepare existing data on the problem being investigated. This indicator can be found during the arrangement of new or previously listed information and occurs both at the beginning of proposing a topic and when revisiting a question, when ideas are recalled.

	Classification of information	This appears when seeking to establish characteristics for the data obtained. Sometimes, when classifying information, it can be presented according to a hierarchy, but the appearance of this hierarchy is not a sine qua non-condition for the classification of information. It is characterized by being an indicator aimed at ordering the elements with which we work.
Group 2	Logical reasoning	Understanding how ideas are developed and presented. It is, therefore, directly related to how thought is exposed.
	Proportional reasoning	It can show how thinking is structured, in addition to also referring to how variables have relationships with each other, illustrating the interdependence that may exist between them.
Group 3	Hypothesis raising	It points out moments in which assumptions are made about a certain topic. This raising of hypotheses can appear either as a statement or in the form of a question (an attitude often used among scientists when faced with a problem).
	Hypothesis testing	Previously raised assumptions are put to the test in these stages. It can occur both in the face of direct manipulation of objects and at the level of ideas when the test is done through thinking activities based on previous knowledge.
	Justification	It appears when, in any statement made, a guarantee is used for what is proposed. This makes the statement gain endorsement, making it more secure.
	Prevision	It is made explicit when an action and/or phenomenon that occurs associated with certain events.
	Explanation	It arises when we try to relate information and hypotheses that have already been raised. Usually, the explanation is accompanied by a justification and a prediction, but it is possible to find explanations that do not receive these guarantees. They are therefore explanations that are still in the construction phase and will certainly be given greater authenticity during the discussions.

The *Base Nacional Comum Curricular* (BNCC) argues that Science Teaching should prioritize pedagogical practices that bring students closer to scientific procedures through investigation (BRASIL, 2018). For Brito and Fireman (2016), activities that prioritize research-based teaching have the potential to promote Scientific Literacy in Basic Education.

Currently, research-based teaching does not aim to grade scientists; Investigative pedagogical practices must aim to “*develop cognitive skills in students, carry out procedures such as developing hypotheses, taking notes and analyzing data, and developing argumentation capacity*” (ZÔMPERO; LABURÚ, 2011, p. 73).

In this context, investigative activities become capable of teaching, in addition to scientific concepts, the procedural contents that surround science (ZÔMPERO; LABURÚ, 2011). For Carvalho (2018), when teaching this syllabus, the teacher must think about teaching through investigation to create opportunities that allow students to think, argue, read critically, and express their ideas.

## II.1 Electromagnetism and virtual simulations in Elementary School

According to the BNCC, the topic of electromagnetism is one of the objects of knowledge related to Physics and, in the Final Years of Middle School, it belongs to the Science curricular component (BRASIL, 2018). Therefore, topics related to Physics and Modern Physics must be worked on with students by the Science teacher, who is responsible for leading the teaching and learning process of this curricular component (VIDEIRA; FRANCISQUINI, 2018).

The teacher in the area of Natural Sciences must go beyond the simple transmission of scientific knowledge: he/she needs to know the practices and procedures of science that result in the construction of scientific knowledge, to provide students with an approach to the processes of scientific investigation (BRASIL, 2018; VIDEIRA; FRANCISQUINI, 2018).

Corroborating this thought, Rosa, Perez, and Drum (2007) state that adding content related to Physics in teaching materials is not enough, since pedagogical practices need to promote Scientific Literacy. Therefore, the teaching and learning process must be able to involve students intellectually in the construction of knowledge (MASSONI; BARP; DANTAS, 2018).

However, one of the biggest challenges for teachers who teach Physics in Elementary and Middle School is to insert the concepts of this discipline, especially abstract and dynamic phenomena such as electromagnetism, through still images (MATOS; MASSONI, 2019; ARAÚJO *et al.*, 2021). Faced with these difficulties, DICT can facilitate the visualization of these concepts through animations and simulations (ZANATTA; SAAVEDRA FILHO, 2020).

Currently, the evolution of DICT and the creation of virtual laboratories, containing interactive simulations that address scientific concepts, allow the reproduction and manipulation of experiments by students themselves on electronic device screens (PAULA, 2017). From this perspective, educational software, through simulators that perform virtual experiments, can make Physics concepts more interesting and meaningful for students (DORNELES; ARAÚJO; VEIT, 2012; NEIDE *et al.*, 2019; ARAÚJO *et al.*, 2021).

Teixeira e Brandão (2003) define educational software as all computer programming created and used as a pedagogical tool, regardless of the level of education or area of knowledge. For Paula (2017), many educational softwares allow students to interact with the object being studied, that is, they can manipulate variables and observe the behavior of phenomena and the changes that happen on the application screen.

It is worth mentioning that virtual simulations do not replace an experiment, as they do not portray the full complexity of a real environment due to the modeling process necessary to produce the simulation, as stated by Heidemann, Araujo, and Veit (2012, p. 972).

*Computational models are “cutouts” of reality, that is, they are computational implementations of specific models, and, as such, they disregard various aspects of the real system, to focus attention on certain particular aspects of nature, which facilitates understanding of the physical phenomenon. Furthermore, the theories*

*involved in the process admit ideal entities and imaginary internal mechanisms. Therefore, computer simulations provide the student interactions with an ideal nature, or rather, with a representation of the object or phenomenon chosen in the modeling process.*

However, virtual simulations can promote learning when used as teaching tools in pedagogical practices (ARAÚJO *et al.*, 2021; COSTA *et al.*, 2021). Furthermore, the interactivity provided by virtual simulations can awaken students' curiosity and desire to learn, since the manipulation of variables favors "*the visualization of characteristics of real or ideational physical phenomena and allows the learner to modify conditions for better observation and analysis*" (ARAÚJO *et al.*, 2021, p. 14).

In this context, inserting simulations into the teaching and learning process of abstract and dynamic concepts related to Physics can make the class more dynamic and meaningful for students, in addition to favoring the process of Scientific Literacy (ARAÚJO *et al.* 2021; PAULA, 2017).

### **III. Methodology**

This work, which is part of the results of a master's degree research, analyzes the application of a didactic sequence carried out with 27 students, aged 13 and 14, in the 8th year of Middle School at a private educational institution, located in the interior of the state of São Paulo.

This article has a qualitative approach, as it seeks to understand how students face research activities and whether they favor the process of Scientific Literacy during Science classes. The focus of this approach is on the dynamic and inseparable relationship between the subject and his world, that is, the context of students' experiences (PRODANOV; FREITAS, 2013; QUINQUIOLO, 2020). From this perspective, "*the interpretation of phenomena and the attribution of meanings are basic in the qualitative research process*" (PRODANOV; FREITAS, 2013, p.70).

Due to the COVID-19 pandemic – which was ongoing in the year of application of the Didactic Sequence – students participated in a rotation system, in the four stages that will be presented in this article, in which some of them were in person and others were online via the Microsoft Teams platform, an applicative to create, share content and resources in a remote and online classroom (MICROSOFT, 2021).

To carry out the planned steps, five teams were formed, two with six students and three with five. Communication between members of the 4 teams took place through WhatsApp (WHATSAPP LLC, 2021), a digital tool that allows the exchange of messages, photos, and videos, in addition to making voice and video calls, and one team used the Microsoft Teams platform. During team meetings, a student acted as a "scribe", that is, responsible for recording the discussions and writing down the hypotheses raised.

Data collection occurred through recordings of the Science classes on the Microsoft Teams platform itself, in which the speeches of students reported in the face-to-face and virtual environment were captured in audio by the notebook used by the teacher in the classroom, also videos made by students during experiments in virtual simulators, as well as direct observation by the researcher together with the subject teacher.

To analyze the data collected through videos and recordings of classes, the participants' statements were transcribed and coded by the researcher manually. Due to copyright and image rights of teenagers under 18, the videos are not available. To verify whether the Scientific Literacy process was favored during the classes provided for in the Didactic Sequence, the indicators proposed by Sasseron (2008).

### III.I Steps for applying the didactic sequence

The first stage was a diagnostic assessment that lasted 55 minutes, with three questions about the content already worked on in previous classes and two with new concepts to be studied. This assessment took place orally and students discussed the issues in their respective teams. At the end, the Science teacher let each team orally present the results of the discussions to everyone in the class.

The second stage was developed in three classes, lasting 50 minutes each. To start the discussion about electromagnetism, covered on pages 108 and 109 of the textbook (FARAGO, 2020) used by the students, the teacher explained the magnetic field of a magnet, showing Figure 1(a) and (b).

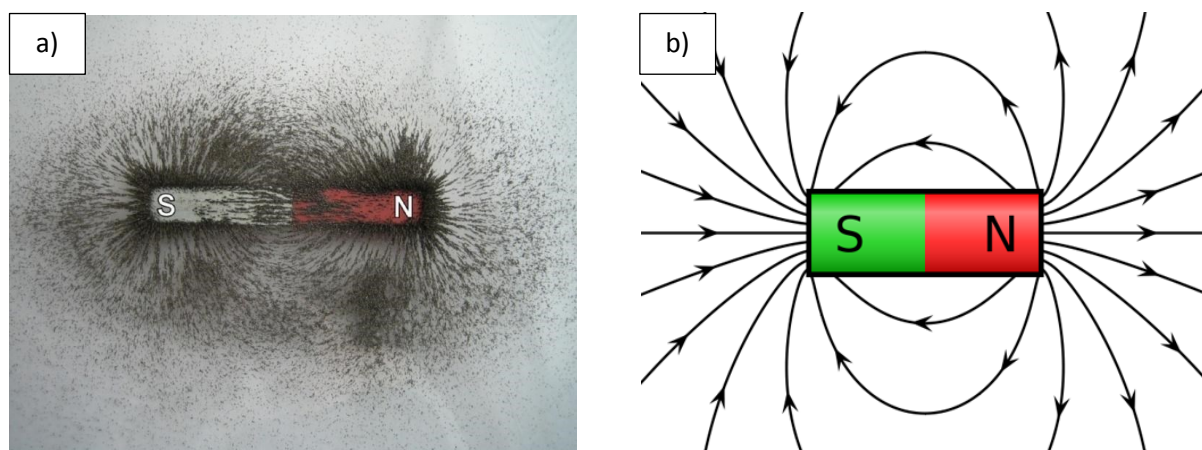


Figure 1 – a) Magnetic field of the magnet represented by iron filings on a sheet of white paper<sup>3</sup>; b) Magnetic field of the bar magnet visually represented by imaginary lines called Magnetic Field Lines<sup>4</sup>.

<sup>3</sup> Fonte: [https://fuches.files.wordpress.com/2009/02/campo\\_magnetico.jpg](https://fuches.files.wordpress.com/2009/02/campo_magnetico.jpg)

<sup>4</sup> Fonte: [https://commons.wikimedia.org/wiki/File:Mafnetic\\_field.png](https://commons.wikimedia.org/wiki/File:Mafnetic_field.png)

The second class was designed for students to raise hypotheses, without using any source of information, for the following question: is it possible to generate a magnetic field from an electric current? Physicist and chemist Michael Faraday concluded that the opposite could also occur, that is, the manipulation of a non-uniform magnetic field can generate electric current, but how is it possible to generate electrical energy using a magnet?

After the teams raised their hypotheses, the students searched for information in the textbook (FARAGO, 2020) and on the internet, intending to confirm or not their hypotheses.

To help assimilate the concept of a permanent magnet's magnetic field, the teacher showed the video “*Desvendando Indução Magnética e superando dificuldades com Física*”<sup>5</sup> between the minutes 6 and 25 seconds up to the minute 10 and 25 seconds. The teacher also presented the video “*Tema 14 - Indução Eletromagnética | Experimento - Lei de Faraday: pêndulo eletromagnético*”<sup>6</sup> to reinforce the concept of Electromagnetic Induction and Faraday's Law.

The third stage was to carry out the experiments through online interactive simulations in the “*Laboratório de Eletromagnetismo de Faraday (2.07.01)*”<sup>7</sup> of the PhET project at the University of Colorado, developed by Carl Wieman (UNIVERSIDADE DO COLORADO, 2021).

For students to raise hypotheses, the teacher showed images captured from the simulator (second column of Chart 2) and asked questions (first column of Chart 2), without making the simulator website available and without consulting the textbook. For each question, they had 10 minutes to discuss and record their hypotheses.

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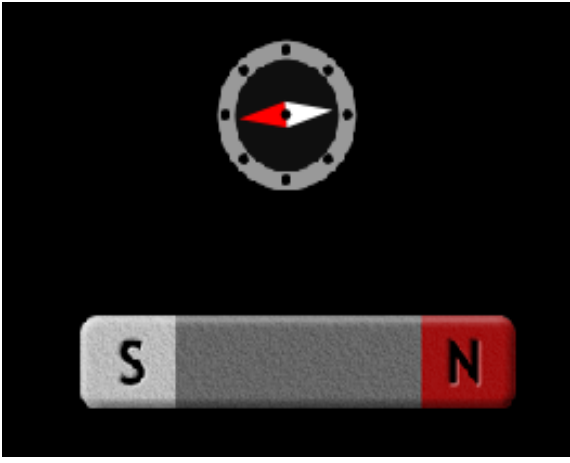
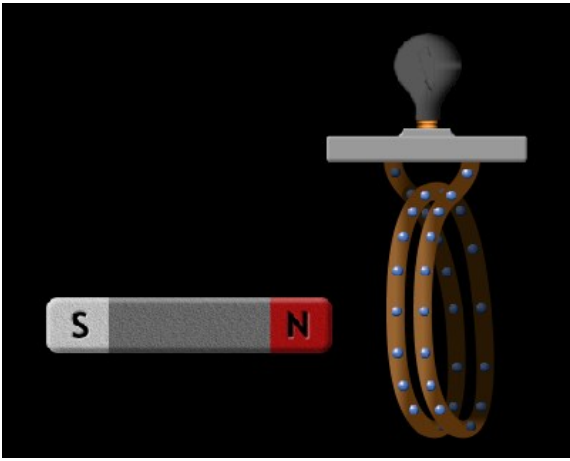
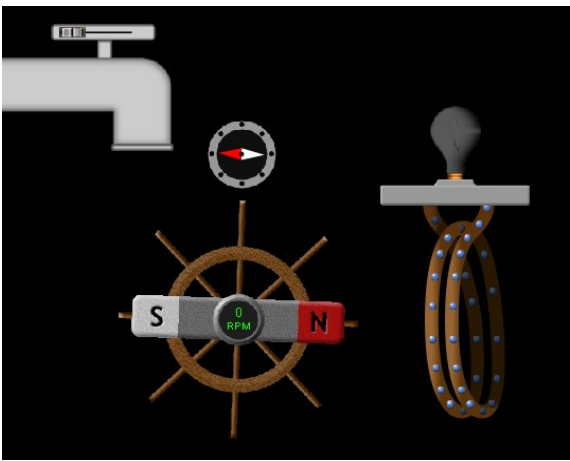
<sup>5</sup> Desvendando Indução Magnética e superando dificuldades com Física. Disponível em: [https://www.youtube.com/watch?v=fHATn0Wzl\\_k](https://www.youtube.com/watch?v=fHATn0Wzl_k). Acesso em: 03 out. 2022.

<sup>6</sup> Tema 14 - Indução Eletromagnética | Experimento - Lei de Faraday: pêndulo eletromagnético. Disponível em: <https://www.youtube.com/watch?v=Rba9EdXO368>. Acesso em: 03 out. 2022.

<sup>7</sup> Laboratório de Eletromagnetismo de Faraday (2.07.01). Disponível em: [https://phet.colorado.edu/sims/cheerpj/faraday/latest/faraday.html?simulation=faraday&locale=pt\\_BR](https://phet.colorado.edu/sims/cheerpj/faraday/latest/faraday.html?simulation=faraday&locale=pt_BR). Acesso em 03 out. 2022.



Chart 2 – Problems to be investigated during simulator experiments. *Figures were taken from PhET Interactive Simulations<sup>2</sup> – phet.colorado.edu.*

<p>i) First questioning:</p> <p>What will happen to the compass if the magnet turns and reverses the poles? Reply in your team chat.</p>	
<p>ii) Second questioning:</p> <p>What will happen if the magnet remains static, that is, stopped? What if it moves in the direction of the loop and performs a back-and-forth movement?</p>	
<p>iii) Third questioning:</p> <p>How to generate energy to light the lamp in the image? What energy transformations occur in the process until light energy is reached?</p>	

After the teams raised their hypotheses, a PDF file was made available with guidelines for carrying out the experiments in the simulator, in which the students confirmed or not the hypotheses.

The experiments of each team were recorded on videos and carried out as an extra-class activity. In them, students narrated the interactions and concepts involved in each simulator experiment and socialized during the class in the next week. A video was selected and shared on the school's social networks.

The fourth stage was for students to associate the content covered in the experiments with the processes that occur inside a hydroelectric plant. To do this, the teacher used a representation of the internal process of a hydroelectric plant<sup>8</sup>.

After presenting the hydroelectric plant's internal process to the students, the teacher asked the following questions:

- a) Which part of the hydroelectric plant was represented by the tap in the last experiment? What type of energy is present in this part?
- b) Which part of the hydroelectric plant was represented by the water wheel in the last experiment? What type of energy is present in this part?
- c) In which part of the hydroelectric plant does the change in the magnetic field generated by the change in polarity of the magnet occur, generating an electric current in the turns, a process similar to what occurred in the last experiment? What types of energy are present in this process? How does one energy transform into another?

## IV. Results and discussion

The results obtained and reported in this article are divided into four sub-items, which follow the order established by the didactic sequence, described in item III.1. Thus, the first sub-item deals with the results and discussion of the diagnostic assessment; the second, those obtained during the students' investigation into the concept of electromagnetism; the third, during experiments in the virtual simulators of the *PhET* project, and the fourth, during the association of experiments with the internal process of a hydroelectric plant.

### IV.1 Diagnostic assessment

In the first question of the diagnostic assessment, "Is it possible to create or destroy energy? Justify.", it was found that the students from four teams had prior knowledge about the principle of energy conservation, as demonstrated by the statement of a member of Team 1: *"Energy is never built in itself, it is transformed from another type of energy. For example, as energy only arises from the tides, which is transformed into electrical energy and cannot be destroyed, it will be transformed"*. Only Team 5 said that the energy could be destroyed. In providing feedback on this question, the teacher helped by reinforcing the principle of

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<sup>8</sup> ELETRÔNICA PRO. Componentes de uma usina hidrelétrica. Disponível em: <http://eletronicapro.blogspot.com/2010/11/componentes-de-uma-usina-hidreletrica.html>. Acesso em 03 out. 2022.

conservation of energy, which had already been studied and remembered at that time, stating that energy cannot be created or destroyed, it will always be transformed.

The second question, *“Where do most of the electrical energy consumed in Brazil come from? Can it be considered renewable or non-renewable?”*, demonstrated that all teams recognized that the majority of Brazilian electrical energy comes from hydroelectric plants, that is, that the country’s main electrical matrix is hydraulic (FARAGO, 2020; BRASIL, 2020). Furthermore, they knew how to classify it as a renewable source, as demonstrated by Team 2’s statement: *“Most of the electrical energy consumed here in Brazil comes from hydroelectric plants. It can be considered renewable because we are always having rain, which contributes to the filling of rivers that generate movement in the turbines of the plants and generate electrical energy”*.

In the third question, *“Have you ever stopped to analyze how much and which equipment in your home uses electricity? How is this energy transformed by these devices?”* It was found that the four teams that responded were able to classify the equipment that requires electrical energy in their homes and identify the energy transformations that occur in them, as demonstrated by Team 1’s speech: *“Yes, in the case of my group, there is a lot of electronic equipment, which transforms electrical energy into practically all types of energy. For example, the lamp transforms electrical energy into luminous energy like the stove, which transforms electrical energy into thermal and luminous energy also through the light of the flame, there is also the example of the blender, which transforms electrical energy into kinetic energy from the movement of propellers, there is also the shower that transforms electrical energy into thermal energy, there is also the computer, which, for example, transforms electrical energy into light energy, thermal energy due to the heat produced and sound energy from the computer speakers, etc.”*. Students of Team 4 were unable to discuss this issue on the Team’s private call, reporting communication problems.

The prior knowledge reported by the teams showed that the students assimilated the topics covered in previous classes, which are planned for the Science discipline at BNCC (BRASIL, 2018). Therefore, there are already substantial ideas anchored for the teaching and learning process on the topic of electromagnetism, which is also determined in the BNCC, in the object of knowledge called energy transformation (BRASIL, 2018).

In this way, the Didactic Sequence can favor meaningful learning for students, as *“the interaction between new potential meanings and relevant ideas in the learner’s cognitive structure gives rise to true or psychological meanings”* (AUSUBEL, 2000, p. 1).

The answers to questions 4, *“Do you know the relationship that the magnet has with the generation of electrical energy?”*, and 5, *“Do you know what electromagnetic induction is?”*, demonstrated that the students did not have relevant knowledge about the relationship between the magnet and electricity, and the phenomenon of electromagnetic induction, as demonstrated by the statements of Teams 2 and 4 for the respective questions: *“we don’t know*

the relationship between a permanent magnet and the generation of electrical energy” and “we don’t know what it is electromagnetic induction”.

Given the above, the diagnostic assessment demonstrated the need to work on this content to make learning meaningful for students.

## IV.2 Investigation into students’ conceptual learning of electromagnetism

To analyze the results of the investigations, the indicators established by Sasseron (2008) were used. To identify those responsible for the statements, we adopted the letters “TS” for Team of Students, accompanied by the identification number of their respective team, and the letter “T” for the teacher, as shown in Charts 3 and 4 with the results of the statements. Investigations were carried out at this stage of the Didactic Sequence.

Chart 3 – Speeches by the teacher and students after investigating the magnetic field and its relationship with electrical energy.

Speeches by the teacher and students	Indicators
<b>T:</b> <i>Guys, now it’s time to discuss the questions you answered as a group. Is it possible to generate a magnetic field from an electric current? What did your group put on, “TS 3”?</i>	-
<b>TS 3:</b> <i>Yes, we think so, because with the help of electric current a magnetic field is generated.</i>	Justification Prevision Explanation
<b>T:</b> <i>Did anyone put anything different?</i>	-
<b>TS 2:</b> <i>Ah, my group stated that when an electric current passes through a conducting wire, a magnetic field is created.</i>	Logical reasoning Justification Prevision Explanation
<b>T:</b> <i>So, do you believe that the magnetic field is influenced by electric current and not the other way around? Is the opposite also true? What do you think?</i>	-
<b>TS 2:</b> <i>I think it could be.</i>	-
<b>TS 4:</b> <i>When a conducting wire carries an electric current it creates or influences a magnetic field.</i>	Logical reasoning Justification Prevision Explanation
<b>T:</b> <i>You are telling me that electric current generates a magnetic field. Can a magnetic field generate electric current?</i>	-
<b>TS 3:</b> <i>Would it be relative?</i>	Hypothesis raising
<b>T:</b> <i>Yes, let’s discuss this. How?</i>	-
<b>TS 4:</b> <i>I think so, one affects the other, right?</i>	Organization of information

<b>T:</b> <i>The proof of this is in the video we just saw. The starting point was motion because energy cannot be created from nothing. So, you saw that it was only possible from the motion of the magnet in the pendulum. Both the magnet in the pendulum and the loop generated an electric current.</i>	-
<b>TS 4:</b> <i>Yes, it has to be moving, right? Stopping doesn't do it.</i>	Prevision
<b>T:</b> <i>Yes, it has to be moving.</i>	-

In the transcription of the speeches of Teams 3, 2, and 4, indicated by the code TS3, TS2, and TS4, respectively, it is clear that the **explanation** for the phenomenon under study was accompanied by the **justification** indicators when reporting that it is possible to generate a magnetic field from an electric current, and the **prediction** that the electric current passed through a conductive wire (action) will create a magnetic field (phenomenon). **Logical reasoning** appears in the way Teams 2 and 4 present their ideas, demonstrating how the phenomenon happens.

In lines 9 and 11 of Chart 3, with codes TS3 and TS4, respectively, the member of Team 3 demonstrated the **hypothesis-raising** indicator by asking a question as a starting point for the debate. The member of Team 4 indicates the **organization of information** when seeking an order for the information highlighted during the discussion.

The speech of the member of Team 4, transcribed in the last code TS4, shows the **prediction** indicator, stating that it is necessary to have the permanent magnet motion (action) to generate electrical energy (phenomenon).

It can be seen, in the students' statements during the discussion transcribed in Chart 3, that the investigations led the teams to discover that the manipulation of the magnetic field, through the motion of a non-uniform permanent magnet, can cause electric current in a conductor wire. Furthermore, they understood that the opposite also occurs, that is, a magnetic field is created by a conducting wire carrying electric current.

Chart 4 – Speeches by the teacher and students after the investigation into electromagnetic induction.

Speeches by the teacher and students	Indicators
<b>T:</b> <i>So, we saw that manipulating the magnetic field could generate an electric current. But how is it possible to generate electrical energy using a permanent magnet?</i>	-
<b>TS 2:</b> <i>We think that it is possible to generate electrical energy through a magnet, sort of like an energy conductor, which will induce the magnetism of the permanent magnet to transform this electromagnetism into electrical energy.</i>	Logical reasoning Hypothesis testing Justification Prevision Explanation
<b>TS 5:</b> <i>As we saw in that video, using the potential energy in the magnet.</i>	Hypothesis testing
<b>T:</b> <i>That's right! Can a permanent magnet stopped next to a loop generate an electric current?</i>	-

<b>TS 4:</b> <i>No, it requires moving the magnet.</i>	Explanation Prevision
<b>T:</b> <i>What does this prove?</i>	-
<b>TS 2:</b> <i>That we need motion, the starting point.</i>	Explanation Prevision
<b>T:</b> <i>Cool! Is the energy generated by the permanent magnet created or transformed?</i>	-
<b>TS 3:</b> <i>Transformed.</i>	Hypothesis testing
<b>T:</b> <i>Why?</i>	-
<b>TS 4:</b> <i>Because it starts with the transformation of motion as the starting point.</i>	Explanation Justification Prevision
<b>T:</b> <i>That's it! What are the energy transformations that occur in this process?</i>	-
<b>TS 2:</b> <i>I think it is the transformation of electromagnetic energy into electrical energy.</i>	Hypothesis testing Explanation
<b>T:</b> <i>Oh yes, look how interesting, we know that it is not created, it is transformed, but where did the transformation begin?</i>	-
<b>Student (it was not possible to identify the team):</b> <i>I think it's in motion.</i>	Hypothesis testing
<b>T:</b> <i>That's right! In the motion. What energy is related to the motion?</i>	-
<b>Student (it was not possible to identify the team):</b> <i>So, it's kinetic energy into electrical energy.</i>	Hypothesis testing Explanation
<b>T:</b> <i>Right! Kinetic energy is transformed into electrical energy through electromagnetic induction.</i>	-

The **hypothesis testing** indicator, identified in the students' statements in Chart 4, can be seen when they answer the teacher's questions about the possibility of a permanent magnet to generate electrical energy, putting to the test the assumptions made by their respective teams during the investigation.

In the first speech by the member of Team 2, with the code TS2, it is noted that he/she uses **logical reasoning** to establish connections between the information raised about electromagnetism in his/her **explanation**, **justifying** his/her statements and making a **prediction** that a magnet can generate electrical current in an electrical conductor.

The statements of one of the members of Teams 2 and 4, transcribed in lines 5, 7, and 11 of Chart 4, demonstrate that the **explanation** indicator appears with the **prediction** that the motion of the permanent magnet is the starting point in the generation of energy. Team 2 also demonstrates, in line 11, the **justification** indicator by ensuring that the transformation of electricity begins with the motion carried out by the permanent magnet.

A member of Team 2 and a student whose team it was not possible to identify made it clear in their speeches, transcribed in lines 13 and 17, that the **explanation** for the transformation into electrical energy was not accompanied by justification; this guarantee was complemented by the teacher when he/she stated that energy is transformed by electromagnetic induction.

In the students' statements, shown in Chart 4, it is clear that the teams were able to understand the phenomenon of electromagnetic induction, as they associated the motion of the permanent magnet with the generation of electrical energy, and the principle of conservation of energy, by stating that electrical energy is the result of the transformation of the kinetic energy of the motion carried out by the permanent magnet.

The analysis of the teams' speeches, given during the discussions led by the teacher to verify the results of the investigations, highlighted the following indicators of Scientific Literacy: Organization of Information (1); Hypotheses raising (1); Hypothesis testing (6); Justification (5); Prediction (8); Explanation (9); and Logical Reasoning (3).

### IV.3 Experiments in the project's virtual simulators *PhET*

To illustrate the experiments, reported in videos made by the teams themselves, we captured images and put together a sequence of experiments. To analyze the speeches, present in the teams' videos, the transcriptions were fragmented and are presented by experiments, being identified as Teams 1 to 4. Team 5 did not make the video: two members reported that they carried out the individual experiments and did not create the video because of difficulty communicating with other team members.

The first experiment is illustrated in Figure 2 and the students' statements during the experiment are transcribed in Chart 5.

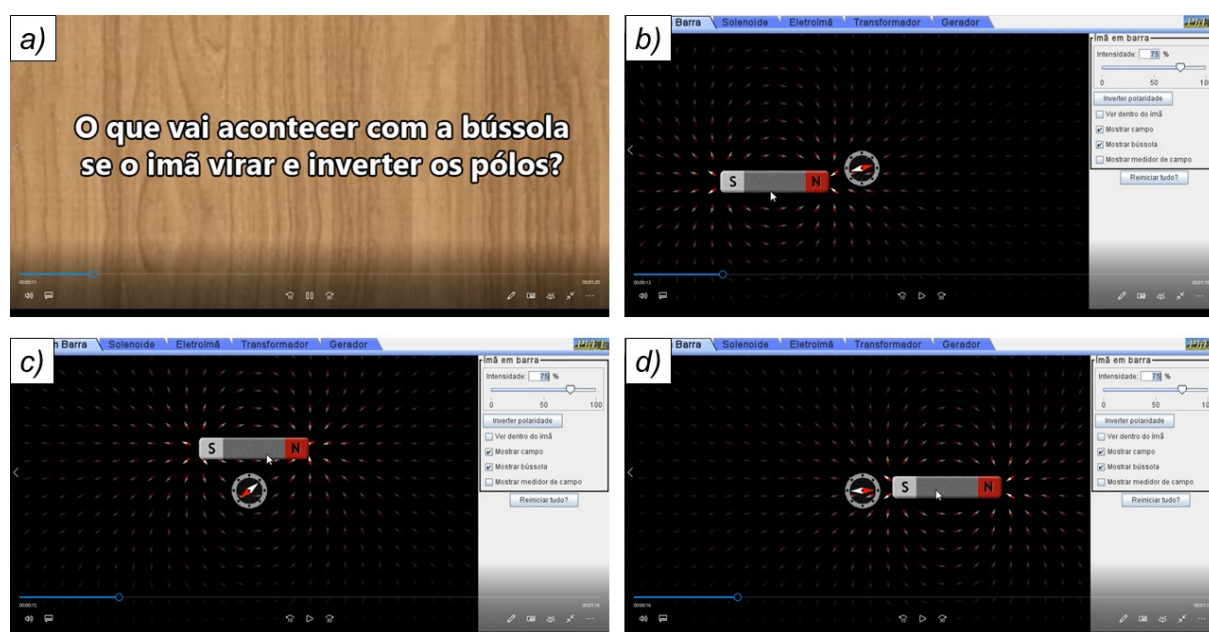


Figure 2 – First experiment: a) proposed problem. Figures b) to d) show manipulations of the permanent magnet around the compass causing changes in the magnetic field, demonstrated by the motion of the compass needle. Images of simulations carried out by students in the PhET Simulator<sup>2</sup> – [phet.colorado.edu](http://phet.colorado.edu).

Chart 5 – Transcription of statements during the first experiment.

Speeches by the teacher and students	Indicators
<p><b>Team 1:</b> <i>Our answer confirmed it was that when an electric current passes near the magnetic compass, it causes the pointer to move or, due to magnetism, it will change the direction.</i></p>	<p>Hypothesis testing Justification Prevision Explanation Logical reasoning</p>
<p><b>Team 2:</b> <i>What will happen to the compass if the magnet flips and reverses the poles?</i>  <i>The group's response was: if the magnet flips the poles, the magnetic compass will also flip the poles, because they repel each other, so if the permanent magnet flips the magnetic compass will also flip.</i>  <i>The answer is right, but it could be more complete, as I describe below: a compass needle is a small permanent magnet, and like any permanent magnet, it is attracted or repelled when approached by another permanent magnet or a magnetic field. If the permanent magnet flips and flips the N and S, north and south poles, the compass needle is also flipped, so if I flip the north and south poles here, the compass needle will also flip, and the directions of the magnetic field induction line it also flip, yeah... The magnetic field is these... these pointers back here, then if they flip, they flip together, you see, it flipped.</i></p>	<p>Hypothesis testing Prevision Justification Explanation Logical reasoning</p>
<p><b>Team 3:</b> <i>In this first video we can see that when we invert the location of the permanent magnet, the magnetic compass pointer returns to its initial position.</i></p>	<p>Organization of Information Explanation</p>
<p><b>Team 4: Member A</b> – <i>What will happen if the permanent magnet flips and reverses poles?</i>  <b>Team 4: Member B</b> – <i>We saw that the compass will invert its poles due to the magnetic field of the permanent magnet.</i></p>	<p>Prevision Explanation</p>

In the analysis of the statements made by Teams 1 and 2 during the videos, which are transcribed in Chart 5, when carrying out the first experiment in the simulator, we can observe the hypothesis test indicator when they confirm and, in the case of Team 2, which reformulated a more precise explanation after manipulating the simulator. The **logical reasoning** indicator can be seen in the way they organize and report their ideas, when **predicting** that the compass pointer would change direction, and providing a **justification** based on the change in the magnetic field, making the explanation more solid and coherent.

In Team 3's speech, two indicators can be noted: the **organization of the information** indicator, when describing and ordering the information obtained during the execution of the experiment, and the **explanation** indicator. However, it is important to highlight that the **explanation** presented is still in the construction phase, as a solid conceptual justification was not provided to support what was being exposed. Team 4's **explanation**



included the prediction that the inversion of the permanent magnet's poles would result in the inversion of the compass' poles due to the change in the permanent magnet's poles.

In the transcriptions of the students' speeches, shown in Chart 5, it is clear that the teams understood the relationship between the magnetic field and the permanent magnet, as they were able to note, during the experiment, that the motion of the permanent magnet caused a change in the magnetic field since they observed and reported the change of direction of the compass needle.

The analysis of the speeches of Teams 1 and 2 showed the presence of the indicators Hypothesis Test, Justification, Prediction, Explanation, and Logical Reasoning. Team 3 presented the Organization of Information and Explanation indicators, and Team 4, the Prediction and Explanation indicators.

The second experiment is illustrated in Figure 3 and the students' statements during the experiment are transcribed in Chart 6.

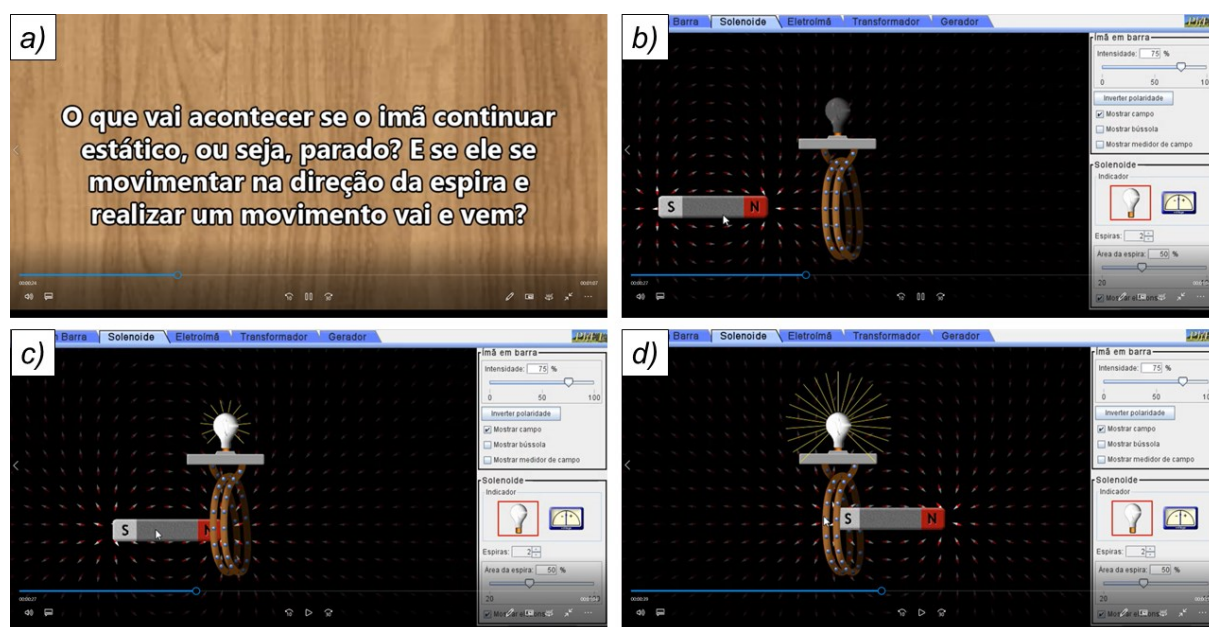


Figure 3 – Second experiment: a) proposed problem; b) magnet stopped and lamp off. In c) and d) the manipulation of the magnet inside the loop in a back-and-forth motion with the lamp on is shown. Images of simulations carried out by students in the PhET Simulator<sup>2</sup> – [phet.colorado.edu](http://phet.colorado.edu).

Chart 6 – Transcription of statements during the second experiment.

Speeches by the teacher and students	Indicators
<b>Team 1:</b> <i>If it stays still it will not generate motion, or else it will not generate an electric current to turn on the light, but if it moves back and forth it will generate an induction, transforming this motion into an electric current, turning on the light, look.</i>	Logical reasoning Hypothesis testing Justification Prevision Explanation
<b>Team 2:</b> <i>Well guys, question 2 is... what will happen if the permanent magnet remains static, that is, stopped? What if it moves toward the coil and performs a back-and-forth motion?</i> <i>Our answer was..., if it stays still nothing happens, but if it moves toward the loop it will generate electrical energy and a light will turn on that is connected to the loop. So, yeah... our answer we think is right, because if the permanent magnet stays still it won't generate any energy, as you can see here. But if we start moving it like this, oh, it will generate electricity, then we think it's right.</i>	Hypothesis testing Prevision Justification Explanation Logical reasoning
<b>Team 3:</b> <i>In this part, we can see that when the permanent magnet is moved it turns on the light.</i>	Organization of Information Explanation
<b>Team 4: Member A</b> – <i>What will happen if the permanent magnet remains static, that is, stopped?</i> <b>Team 4: Member B</b> – <i>If the permanent magnet stays still, nothing will happen.</i> <b>Team 4: Member A</b> – <i>What if it moves towards the coil and performs a back-and-forth movement?</i> <b>Team 4: Member B</b> – <i>If it moves back and forth, the light will keep turning on and off, like that.</i>	Prevision Hypothesis testing Explanation

When carrying out the second experiment, it is clear that Teams 1 and 2 **tested** and confirmed their **hypotheses**. During the **explanations**, they included the **prediction** that it was necessary to move the permanent magnet to light the lamp, as well as the **justification** that the result was able to generate electrical energy in the loop. These elements indicate the use of **logical reasoning** in structuring and exposing thoughts.

In Team 3's speech, the **organization of information** indicators are noted when describing and ordering the information obtained during the execution of the experiment, and the indicator **explanation**, which was not accompanied by a solid conceptual justification as a guarantee to support the idea and the thought reported.

By manipulating the experiment, Team 4 performed **hypothesis testing** and verified that their assumption was correct. It is possible to observe, in the transcript of the Team's video, that the **explanation** indicator was accompanied by the **prediction**, stating that the permanent magnet at rest did not produce any effect, but its movement was able to turn the lamp on, but without a solid guarantee to justify this phenomenon.

It can be seen, in the transcriptions shown in Chart 6, that the second experiment allowed the teams to understand the phenomenon of electromagnetic induction, as they demonstrated and explained that the permanent magnet moving close to the spiral generated electric current, responsible for turning the light on.

The analysis of the speeches of Teams 1 and 2 showed the presence of the indicators of Hypothesis Testing, Justification, Prediction, Explanation, and Logical Reasoning. The analysis of Team 3's speech demonstrated the indicators Organization of Information and Explanation and Team 4's speech showed the indicators of Prediction, Hypothesis Testing, and Explanation.

The third experiment is illustrated in Figure 4 and the students' statements during the experiment are transcribed in Chart 7.

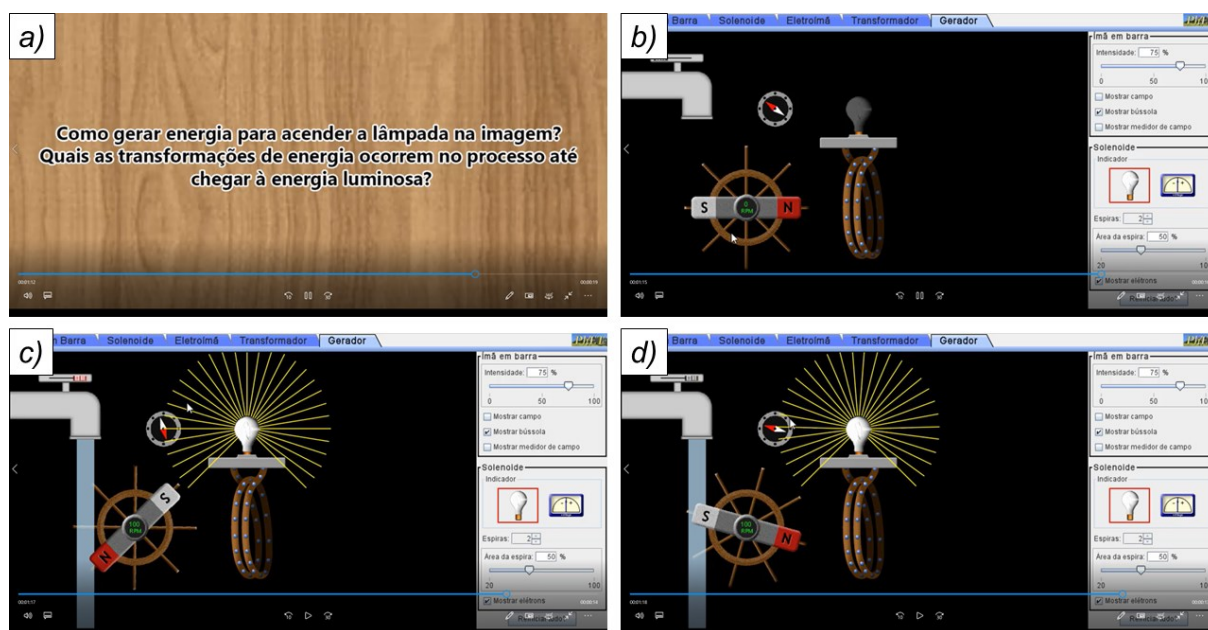


Figure 4 – Third experiment: a) proposed problem; b) starting point, tap closed. In c) and d) the manipulation by opening the tap, the fall of water rotating the magnet, and the generation of energy in the coil to light the lamp up are shown. Images of simulations carried out by students in the PhET Simulator<sup>2</sup> – [phet.colorado.edu](http://phet.colorado.edu).

Table 7 – Transcription of statements during the third experiment.

Speeches by the teacher and students	Indicators
<b>Team 1:</b> <i>The tap must have 100 rotations per minute, causing the force of the water flow, which will rotate the tiller (water wheel), making the magnet to rotate, which will move the magnetic compass direction and increase the electrical current by around the lamp, and thus generating enough electricity to keep it on.</i>	Logical reasoning Proportional reasoning Hypothesis testing Justification Prevision Explanation
<b>Team 2:</b> <i>The question was how to generate energy to turn the light on in the image. What energy transformations occur in the process until light energy is reached? We answered that to generate energy we have to open the tap that will flip the permanent magnet, which with the motion of the permanent magnet will generate electrical energy that will turn on the light and the transformation will be from kinetic energy to kinetic energy again and from spiral to the lamp will be electrical energy by induction. We evaluated it by carrying out this experiment here and the theory was correct, because when we opened the tap the wheel started to rotate, then the permanent magnet that was stuck to the wheel also started to move and the light turned on.</i>	Hypothesis testing Prevision Justification Explanation Logical reasoning
<b>Team 3:</b> <i>To leave the light on, just turn on the tap, as the tiller (water wheel) will start to rotate and so will the permanent magnet, providing energy that will leave the light on.</i>	Organization of Information Explanation Prevision
<b>Team 4: Member A</b> – <i>How to generate energy to turn the light on in the image?</i> <b>Team 4: Member C</b> – <i>They generate energy by turning the water wheel.</i> <b>Team 4 Member A</b> – <i>What energy transformations occur in the process until light energy is reached?</i> <b>Team 4 Member C</b> – <i>It is the kinetic energy that changes to mechanical energy and then turns into electromagnetic energy to electrical energy and then into light energy when the light turns on.</i>	Hypothesis testing Prevision Justification Explanation Logical reasoning

In the narrations of the third experiment, transcribed in Chart 7, it is noticeable that Teams 1, 2, and 4 **tested the hypotheses** formulated during the experiment. It is also possible to notice the **logical reasoning** indicator in the way students structure their ideas and present the concepts developed by the teams during the activity. In the **explanations, prediction** indicators can be seen, when they state that the electricity needed to keep the lamp on was generated by the fall of water and the motion of the permanent magnet close to the loop; and **justification** when they report that the phenomena observed during the experiment resulted in energy transformations. The **proportional reasoning** indicator appears in Team 1's transcript when establishing a relationship between the amount of water released by the tap, the rotation of the water wheel, the electrical current generated, and the result in the lamp on.

In Team 3's speech, we can see the **organization of information** indicators when describing and ordering the information obtained during the execution of the experiment, and the **explanation** indicator, which was accompanied by the **prediction** that the falling water moved the magnet to generate the energy able to make the lamp on

The teams' statements, transcribed in Chart 7, demonstrate that the students, when carrying out the third experiment, had contact with a process very similar to what happens in most hydroelectric plants, as they were able to associate the waterfall with opening the tap, with the generation of electrical energy, through the transformation of the kinetic energy caused by the rotation of the permanent magnet near the loop into electricity through electromagnetic induction, which, in turn, was responsible to light the lamp on during the experiment.

The analysis of Team 1's speech showed the presence of the indicators Hypothesis Test, Justification, Prediction, Explanation, Logical Reasoning, and Proportional Reasoning. Teams 2 and 4 showed the presence of the indicators Hypothesis Test, Justification, Prediction, Explanation, and Logical Reasoning, and Team 3 the indicators Organization of Information, Prediction, and Explanation.

Team 3 only narrated the experiments, without presenting the hypotheses raised and the concepts worked on. The fact that the experiment was carried out as an extra-class task, without the teacher's supervision, may have generated a lack of understanding of the proposal, as one member reported that they had carried out the hypothesis survey and discussed the concepts, but felt that it was not necessary to put on video.

#### IV.4 The experiments and internal processes of hydroelectric plants

The teacher's statements, when presenting the questions comparing Figure 2 with the third experiment, and those of the students when reporting the team's discussions, are presented in Charts 8 to 10, in the following items:

##### i) First questioning:

Chart 8 – Transcript of statements during the first questioning.

Speeches by the teacher and students	Indicators
<p><b>T:</b> <i>We will associate the experiments with the operation of a hydroelectric plant. I will read the question and in team order, we will discuss the results.</i></p> <p><i>The first question is: Which part of the hydroelectric plant did the tap represent?</i></p> <p><i>What type of energy is present in this part?</i></p> <p><i>Come on Team 1, what did you put in?</i></p>	-
<p><b>TS 1:</b> <i>So... the part represented would be the reservoir and the control port and we think that the energy would be gravitational and kinetic.</i></p>	<p>Classification of information</p> <p>Hypothesis testing</p>

<b>T:</b> Team 2?	-
<b>TS 2:</b> Our group stated that the tap represents the control port, I think it is what releases the water from the reservoir, just like the tap, and the energy present in this part is hydroelectric power.	Classification of information Justification Explanation
<b>T:</b> Is hydroelectric a type of energy? I'm not going to dictate the answers, I'm going to ask questions, OK? Is hydroelectric a type of energy?	-
<b>TS 2:</b> Yes, because it is the energy that is transformed by the motion of the water.	Hypothesis raising Explanation
<b>T:</b> So, what type of energy was formed with the motion of the water?	-
<b>TS 2:</b> The electric. Oh, it's true, it's the hydroelectric plant that generates electricity. So the type of energy is electrical.	Logical reasoning Justification Explanation
<b>T:</b> That's right! Let's go, Team 3.	-
<b>TS 3:</b> We think it's the control port. We think energy is kinetic.	Classification of information Hypothesis testing
<b>T:</b> Team 4?	-
<b>TS 4:</b> Our group stated that it is the tap that represents the control door, because it is what controls the water, and the energy is gravitational potential energy because it is the force of gravity that will make the water fall generate the energy there.	Classification of information Logical reasoning Proportional reasoning Justification Prevision Explanation
<b>PT Team 5?</b>	-
<b>TS 5:</b> We think it represents the water that is trapped in the reservoir and the control port. The energy is gravitational potential because the water is under pressure due to gravity.	Classification of information Logical reasoning Justification Explanation
<b>T:</b> Guys, I'm going to ask you some questions so we can reflect on this. You open the tap and the water passes through, I'm thinking of a barrier, perhaps this is the question that some asked to say that it would be the control door, but for the tap to actually work, what does it need?	-
<b>TS 2:</b> Of the water, it is the reservoir and dam, which are being controlled by the control gate.	Organization of information Classification of information Logical reasoning Justification Explanation
<b>T:</b> That's right! So, what type of energy is present in this part, whether in the control gate, in the reservoir, or the dam?	-

<b>TS 4:</b> <i>Kinetic energy because of the motion of falling water.</i>	Hypothesis testing Justification Explanation
<b>T:</b> <i>But what kind of energy acted on the water to make it fall?</i>	-
<b>TS 2:</b> <i>Gravity energy, because it is the force of gravity that makes the water fall. Does it have a specific name or is it gravity energy?</i>	Hypothesis testing Justification Prevision Explanation
<b>TS 5:</b> <i>Our group stated that it is gravitational energy.</i>	-

In Team 1's speech, transcribed in Chart 8, it was possible to identify the **classification of information** indicator, as they established the relationship between the simulator tap, the reservoir, and the control port represented in the hydroelectric plant. Furthermore, the **hypothesis testing** indicator can be observed, as the student stated that the types of energy involved in this part are gravitational and kinetic, putting to the test the assumption raised by this Team based on the knowledge acquired in the previous stages.

In Team 2's first speech, it is possible to identify the **classification of information** indicator. The student established relationships between the elements of the experiment and those represented in the hydroelectric plant. The **explanation** provided for the association of the tap with the control port was accompanied by a **justification**, highlighting that in both cases water is released for energy generation.

Regarding the type of energy represented in this part, the teacher had to direct the team through new questions, as described in the fifth line of the table, since the student's answer was wrong. One of the members of Team 2, whose speech is transcribed in the sixth line, presented a hypothesis to be confirmed or refuted, thus showing the **hypothesis-raising** indicator. In turn, the third response, transcribed in the eighth line, used **logical reasoning** to **explain** the phenomenon, accompanied by a **justification**, which stated that the energy produced in the hydroelectric plant is electrical energy.

Team 3 demonstrated the **classification of information** indicator in their speech, as the students established relationships between the elements of the experiment and the elements of a hydroelectric plant. By stating that the energy involved in this specific part is kinetic, they subjected the team's results to **hypothesis testing**, seeking to verify the assumption made.

In the speech recorded in the twelfth line, it is noticeable that the member of Team 4 used **classification of information** when establishing connections between the experiment tap and the control port. The presentation of thought demonstrated the presence of **logical reasoning** and **proportional reasoning** since the **explanation** included a **justification** and a **prediction** that both items mentioned influence the amount of water and the flow, due to the force of gravity (gravitational potential energy), to generate energy.

In the speech of the member of Team 5, transcribed in the fourteenth line, it was possible to note the **classification of information** indicator, since the member established

connections between the experiment tap, the reservoir, and the control port. The **explanation** provided, by mentioning that the energy involved is gravitational potential energy, demonstrated the use of **logical reasoning**. The **justification** indicator can be seen when the student states that the pressure exerted on the water in the reservoir occurs due to the force of gravity.

The answer provided by a member of Team 2, in the sixteenth line, makes it clear that the student presented an arrangement of the data obtained previously and established relationships between them, indicating the characteristics of the indicators of **organization** and **classification of information**. Furthermore, the **explanation** and **justification** provided for the representation of the tap as the control port, due to its function in controlling the flow of the reservoir and dam, allows us to identify the logical **reasoning indicator**.

It is possible to notice that the student from Team 4, in his/her speech transcribed in the eighteenth line, applied thought and used the knowledge acquired to provide an answer, revealing the **hypothesis testing** indicator. The **explanation** given for the type of energy to be kinetic energy gained support when the student **justified** that water moves when passing through the control door.

Team 2's speech, transcribed in the twentieth line, reveals that the hypothesis initially raised by the team was refuted, but they managed to reach the correct answer based on the discussions that took place in class. This demonstrates the **hypothesis testing** indicator. By stating that the type of energy involved is gravitational energy, the student sought to **justify** and make a **prediction** related to the force of gravity exerted on the water, which would result in its fall. This approach allowed the relationship between information and guaranteed the **explanation** provided.

The first question, presented by the teacher in Chart 8, sought to lead students to establish relationships between the tap in the experiment and the reservoir and the control port of a hydroelectric plant, as well as the type of energy involved in that part.

It can be seen, from the transcription of the students' speeches, that they understood the types of energy involved at that moment, as they reported gravitational potential energy, in the action of gravity as responsible for the waterfall, and kinetic energy, as a result of water movement, which occurred during the experiment when opening the tap and associated it with the operation of the control door of the hydroelectric plant.

The analysis of this fragment demonstrated the presence of the following Scientific Literacy indicators: Classification of Information (6); Organization of Information (1); Hypotheses raising (1); Hypothesis testing (4); Justification (7); Prediction (2); Explanation (8); Logical Reasoning (4); and Proportional Reasoning (1).



**ii) Second questioning:**

Chart 9 – Transcript of statements during the second questioning.

Speeches by the teacher and students	Indicators
<b>T:</b> <i>Now let's move on to question 2. Which part of the hydroelectric plant was represented by the water wheel? What type of energy is present in this part? Group 1?</i>	-
<b>TS 1:</b> <i>Well, I think the part it represents would be the turbine and the energy in that part is also kinetic.</i>	Classification of information
<b>T:</b> <i>Team 2?</i>	-
<b>TS 2:</b> <i>The same thing, we say that the part is the turbine and the energy is kinetic.</i>	Classification of information
<b>T:</b> <i>Team 3?</i>	-
<b>TS 3:</b> <i>Turbine and kinetic energy too.</i>	Classification of information
<b>T:</b> <i>Team 4?</i>	-
<b>TS 4:</b> <i>We said that it is the turbine and the kinetic energy, because of the motion, that it is rotating.</i>	Classification of information Logical reasoning Justification Explanation
<b>T:</b> <i>Team 5?</i>	-
<b>TS 5:</b> <i>The turbine and kinetic energy too.</i>	Classification of information

The statements from Teams 1 to 5, transcribed in Chart 9, reveal the presence of the **classification of information** indicator. This can be observed when these teams compare and establish relationships between the motion of the water wheel in the simulator and the turbine, in addition to reporting that it is the kinetic energy that is present in this part of the hydroelectric plant.

Team member 4 presented his/her thoughts through an **explanation** accompanied by **justification**, highlighting that the rotational motion of the water wheel and turbine is due to kinetic energy. This clear and logical approach reflects the presence of the **logical reasoning** indicator in your argumentation.

In the transcriptions of the speeches, shown in Chart 9, it is clear that the objective of getting the teams to compare the turbine of a hydroelectric plant with the water wheel present in the experiment was achieved since they made this comparison correctly and identified that the type of energy present in that part was kinetic energy, generated by the motion carried out by them.

It was evident, in the analysis of this fragment, the presence of the following Scientific Literacy indicators: Classification of Information (5); Justification (1); Explanation (1); and Logical Reasoning (1).

### iii) Third questioning:

Chart 10 – Transcript of statements during the third questioning.

Speeches by the teacher and students	Indicators
<b>T:</b> <i>Let's go to question 3. In which part of the hydroelectric plant does the change in the magnetic field generated by the change in polarity of the permanent magnet occur, generating an electric current in the turns? What types of energy are present in this process? How does the transformation of one energy into another occur? Come on, Team 1?</i>	-
<b>TS 1:</b> <i>I think this would be in the generator and the turbine because the generator would have the spirals and the turbine has the permanent magnet, so we think that the motion of this turbine will generate energy in the generator.</i>	Classification of information Logical reasoning Justification Prevision Explanation
<b>T:</b> <i>Team 2?</i>	-
<b>TS 2:</b> <i>We say that it is in the generator and transformer because the motion of the permanent magnet close to the spiral will cause... electromagnetic induction, which will be transformed into electrical energy.</i>	Classification of information Logical reasoning Justification Prevision Explanation
<b>T:</b> <i>Team 3?</i>	-
<b>TS 3:</b> <i>The generator and the transformer.</i>	Classification of information
<b>T:</b> <i>Why?</i>	-
<b>TS 3:</b> <i>It is because the generator will generate energy received from the electromagnetic induction of the kinetic energy of the turbines and the transformer will transform it into electrical energy.</i>	Logical reasoning Justification Prevision Explanation
<b>T:</b> <i>Team 4?</i>	-
<b>TS 4:</b> <i>This happens at the generating plant.</i>	Classification of information
<b>T:</b> <i>This happens in the power plant. What is the difference between the power plant and the transformer?</i>	-

<b>TS 4:</b> <i>It's because the power plant seems to group the turbines, the generator, and the transformer. The kinetic energy from the movement of the turbines will generate energy by induction in the generator and the transformer will take this energy and transform it into electricity.</i>	Classification of information Justification Prevision Explanation
<b>T:</b> <i>Team 5?</i>	-
<b>TS 5:</b> <i>Our group thought it was the generator, transformer, and power lines.</i>	Classification of information
<b>T:</b> <i>Wouldn't the power line be the transmission part? Is it part of the transformation?</i>	-
<b>TS 5:</b> <i>True, it just transmits.</i>	Hypothesis testing
<b>Another TS 5:</b> <i>So, it's at the power plant, right? Seeing what others have said, I think that the kinetic energy of the motion of the turbine close to the generator will generate electrical energy through magnetic induction.</i>	Organization of information Logical reasoning Justification Prevision Explanation

In the transcriptions of the speeches of Teams 1 to 4, displayed in Chart 10, it was possible to identify the **classification of information** indicator, as they classified and established relationships between the elements covered in the context. Furthermore, the **justification** presented for the transformation of kinetic energy into electrical energy included a prediction, describing that the motion of the turbines would be responsible for magnetic induction for the generation of energy, which would later be transformed into electricity by the transformer. This structured **explanation** and the way the thought was exposed reveal the indicator of **logical reasoning**.

In Team 5's first speech, it was possible to identify the **classification of information** indicator, as they classified and established relationships between the elements covered in the context. The second statement revealed that, after the teacher's intervention, the team recognized that they had initially answered incorrectly about the power lines. However, they understood that these lines do not participate in the transformation of energy, but rather play the role of transmission, a fact that indicates the presence of the **hypothesis testing** indicator, in which the team reviewed and corrected their initial assumption based on the information provided by the teacher

In the last speech by team member 5, it is possible to observe the presence of the **organization of information** indicator, as he/she sought to structure the information discussed during the speeches of colleagues from other teams to formulate his/her response. Furthermore, the way the thought was reported reveals the presence of **logical reasoning**. His/her **explanation** includes a **justification** and a **prediction**, emphasizing that the kinetic energy generated by the motion of the turbine can be transformed into electrical energy by the generator through electromagnetic induction. This approach demonstrates a secure and more grounded explanation.

The teams' statements, transcribed in Chart 10, demonstrate that the students, during the experiments in online simulations, related the fundamentals of electromagnetism with the generation of electrical energy, as they were able to understand the energy transformations that occur, through electromagnetic induction, in the production process of a hydroelectric plant.

The analysis of this fragment demonstrated the presence of the following Scientific Literacy indicators: Classification of Information (5); Organization of Information (1); Hypothesis testing (1); Justification (5); Prevision (5); Explanation (5); and Logical Reasoning (5).

The evidence of Scientific Literacy indicators, observed and reported during all activities proposed in the Investigative Teaching Sequence, described in this work, are organized and separated by team in Table 1.

Table 1 – Evidence of Scientific Literacy indicators observed in each Team.

Group of indicators	Scientific Literacy indicators	Team 1	Team 2	Team 3	Team 4	Team 5
1	Organization of Information	0	1	3	1	1
	Classification of Information	3	4	3	3	3
2	Logical Reasoning	3	7	1	5	2
	Proportional Reasoning	0	0	0	1	0
3	Hypothesis raising	0	1	1	0	0
	Hypothesis testing	4	6	2	4	1
	Justification	4	10	2	7	2
	Prevision	4	8	3	9	1
	Explanation	4	13	5	10	2

It can be seen in the Table 1, based on the analysis of the students' speeches given during the Didactic Sequence and transcribed in the fragments presented in this work, that the Scientific Literacy process was favored, as how the teams organized and classified the information obtained during the investigative activities demonstrated the presence of the first group of indicators proposed by Sasseron (2008). The structuring of thought, how ideas were reported and the logic when interpreting the behavior of natural phenomena demonstrated the presence of indicators from the second group. The third group can be noted by the teams' ability to establish relationships between the phenomena studied in that context.

Although the three groups of indicators appear in the speeches of all teams during the Investigative Teaching Sequence, they do not appear with the same frequency between teams. This fact corroborates the study by Sasseron (2015), stating that Scientific Literacy is a continuous process and does not have an endpoint or closure. Just like scientific knowledge

and the advancement of science, it must be constantly constructed, through the analysis of new situations.

In this context, the difference between the frequencies of indicators portrays the reality, in which students develop in a heterogeneous way, as individual factors and the environment in which they are inserted influence them, including interaction with colleagues and teachers in the classroom of class (VYGOTSKY, 1978).

## V. Final remarks

This work aimed to understand and report how activities with an investigative approach, using online simulations from the *PhET* project, can promote the process of Scientific Literacy in Elementary School students, through the indicators proposed by Sasseron (2008).

The presence of the three groups of Scientific Literacy indicators, proposed by Sasseron (2008), demonstrates that the online simulations of the Faraday Electromagnetism Laboratory (2.07.01) of the *PhET* project, when used with investigative approaches in didactic sequences, can be considered tools capable of providing experimentation to students, especially in places where the real experiment is less viable.

It is worth noting that the restricted number of participants limits our ability to establish more incisive conclusions about the relationship between investigative activities and Scientific Literacy. However, given the results obtained, it is understood that online interactive simulations, used as a pedagogical tool in an investigative didactic sequence, favored the Scientific Literacy process for this group of Elementary School students, even in the scenario imposed by the COVID-19 pandemic.

Finally, it is important to highlight that monitoring discussions during meetings between students in their respective teams should be better explored, since they took place remotely; and should be the subject of future work. The analysis carried out in this study allows us to infer information about team development but offers few individual insights. This fact also limits the identification of possible indicators of Scientific Literacy, mainly the survey of hypotheses and the serialization of information, which may have occurred in video calls parallel to the face-to-face classroom and online on the Microsoft Teams platform.

Concerning the learning of teams in the 8th year of Middle School, the results indicate that the use of online interactive simulations from the *PhET* project and the interactions mediated by DICT, used in the didactic sequence described in this article, contributed positively to the teaching and learning process of abstract physics phenomena, such as the theme “Energy and Electromagnetism”, since they were able to relate the fundamentals of electromagnetism with the generation of electrical energy in hydroelectric plants.

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