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Investigative didactic sequence for the teaching of electrochemistry addressing the disposal of batteries

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Abstract: Electrochemistry is an essential context for understanding current energetic technological processes, especially those that use batteries. On the other hand, it is one of the most neglected subjects in the classroom for reasons of associated complexity. Because of this, we have sought new methodological strategies to overcome the difficulties encountered in teaching practice. Thus, this research aims to investigate the possible contributions of a didactic sequence on the disposal of batteries from the teaching by research for the learning of electrochemistry. A qualitative methodology, a case study, applied in a high school class was adopted. The sequence consisted of six methodological steps: implementation of the problem situation; developed hypotheses; a class on electrochemistry; investigative experiment on the decomposition of batteries in aqueous solutions; systematization and communication of results. The results showed that before the application of the didactic sequence, most of the students did not know the dangers that improper disposal of batteries causes to the environment and did not understand how galvanic cells generate electrical energy from a redox reaction. After the sequence was developed, most students were able to identify and conceptualize the main electrochemical terms studied from a critical thought about this problem.

Keywords: didactic sequence; experimentation; electrochemistry; batteries

1 Introduction

As the literature points out, chemistry classes are considered the least important uninteresting, and unmotivating by most students, since they claim a certain distance between theory and the technological and social world (Santos et al., 2013). According to Medeiros (2022), the teaching of Chemistry follows in a traditional and decontextualized way with daily life, generating students’ disinterest in the subject even the chemistry is present in our daily life. Silva and Soares (2013) reported that learning chemistry should enable students to give students a critical view of the chemical transformations that occur in the physical world, as well as to judge the information acquired in the media, school, and society. From there, the students will make their decision and thus interact with the world as a citizen.

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In this perspective of bringing new paths that contribute to the teaching and learning of chemistry, the present study aims to develop the concepts inherent to the disposal of “dead” batteries articulating electrochemistry, based on an active methodology, teaching by investigation. The option for these concepts happened because they were highlighted as one subject of great difficulty for students to understand, as presented in previous works (Barreto et al., 2017).

On the other hand, according to the literature (Brett & Oliveira-Brett, 2020; Nakhleh, 1992; Ogude & Bradley, 1994; Sanger & Greenbowe, 1997), electrochemistry has been regarded as one of the most difficult chemistry topics in which both students and teachers have difficulties. However, much work has been done in identifying learning difficulties, and yet, learners continue to experience the same difficulties in today’s classrooms.

According to Rahayu et al. (2022), while the grand mean trend in understanding electrochemistry concepts from high school through university study did show some improvement, the mean scores remained relatively low, and the year group means per item showed no such trend exacerbated by items having varying levels of difficulty.

According to Oliveira et al. (2012), people understand things better when they experience the practice, leading to the best way to teach the students starting when they have direct contact with the object of study. The school plays the role of bringing the students’ knowledge and understanding of the problems that are around us.

The development and consumption of electronics have grown expressively in the past years due to the globalization process and fast industrialization of the popular countries, with the ascendant economy, especially Brazil. For that reason, the production of batteries has raised, and the use of these energetic devices has become more often in many places. Even though, most used batteries do not reach their correct destination, being mixed with household waste. The recycling percentage of e-waste, especially batteries, is negligible since there is no consolidation of reverse logistics business policies for this type of waste (Faria & Oliveira, 2019).

As an alternative, the authors have proposed an experiment using dead batteries that probably would have gone to the school’s trash as an investigative teaching method to sensitize students about electrochemistry, electronic recycling, and environmental safety.

Given the above, the following research problem was conceived: “How does a Didactic Sequence (DS), based on teaching by investigation, enable the construction of chemical knowledge articulated to the issue of battery disposal, within the content of electrochemistry?”

A Didactic Sequence (DS), according to Zabala (1998, p. 18), is “a set of ordered, structured and articulated activities, aligned to achieve certain pedagogical objectives, which have a beginning and an end known both by teachers as well as the students”.

In this study, we thought of using a DS that would allow the students to reflect on the potential behind this activity and that could, at the same time, construct/systematize knowledge to overcome the obstacles around dichotomized teaching in which theory, practice, teaching, and research do not relate to one another. That’s why we used the Investigative Teaching Sequences (SEI), which according to Carvalho (2013) are sequences of activities covering the content of the school program in which each of the activities is planned, from the point of view of the material and interactions between participants. This sequence aims to provide students with conditions to bring their previous knowledge to initiate new ones; having their own ideas and being able to discuss them with their classmates and the teacher; promote scientific literacy and enable them to understand knowledge already structured by previous generations.

Therefore, an investigative teaching sequence needs to present some key activities, such as: a problem, a knowledge systematization activity, an activity that promotes contextualization and an evaluation (Carvalho, 2013).

In an investigative teaching sequence, Carvalho (2013) adds that the teaching material provided should include a contextualized question, and based on the student’s previous ideas, hypotheses will be raised and tested to resolve the issue presented. With these definitions, it may seem like something very difficult to do in the classroom, and what we report next is the opposite, it is possible and feasible. Figure 1 illustrates the steps of the investigative teaching sequence developed and presented as follows:
According to Sasseron and Machado (2017), experimental activities should pose a problem to students that allows triggering an investigation process. The question that will inform the problem is an essential element for the good performance of the activity, but it is not the only one. Must be emphasized that an investigative experimental activity has to be planned, so the materials are available to the students, then the variables intended to be studied will be studied. Therefore, planning should take care of the proposed problem, the available materials, and the interactions between them, with the materials, and with the teacher.

Thus, this study aims to investigate the possible contributions of a didactic sequence on the disposal of batteries from the investigative teaching sequences using as a theme the study of electrochemistry.

2 Methodology and methods

In this section, we present the study and development stages including the collection of data. Data collection and analysis involve a qualitative method. All participants were asked to sign an informed consent.

According to Oliveira (2005) qualitative research can be characterized as an attempt to explain in depth the meaning and characteristics of the result of information obtained through interviews or open questions, without quantitative measurement of characteristics or behavior.

The methodological tool adopted was the case study, which according to Severino (2016) the case chosen for the research must be significant and well representative, to be able to base a generalization to analogous situations, authorizing inferences.

3 Participants in the study

The DS was developed and applied in a class comprising 30 students at the high school at a Public Reference School of the State Network, located in the city of Recife, in the discipline of chemistry. They are students at an upper secondary school. They are final year students (age group between 17 and 18), with the same chemistry background. The demographic aspects of the students are similar among themselves, once, the location of their residences is next to the school. There are not any economic discrepancies among them as well.

Students were divided into six groups of five students each. The groups were named G1, G2, G3, G4, G5 and G6. The DS was constructed as recommended by Zabala (1998), which states that one of the instruments to differentiate the educational practice is the application of an DS as a teaching–learning strategy and that it consists of a sequence of interconnected activities that are designed to teach a certain content.
4 Design and development of the didactic sequence

The design presented here focused on the development of a didactic sequence on the content of electrochemistry within the theme of the disposal of batteries. The proposed DS consisted of six steps that took place over four weeks with 100-min classes, as described following:

4.1 Stage 1. Prior knowledge of the theme

The DS was initiated as the application of an individual preliminary questionnaire, in which the relationship between electrochemistry and batteries was discussed. Initially, the focus was to investigate the students' prior knowledge of the theme. Soon after, the researchers promoted a discussion with the students on the collected data to introduce the chosen content.

To better illustrate the contribution of DS in assisting the student in decision-making on issues involving the relations between electrochemistry and batteries, besides their effects on the environment, the results of the questionnaire were analyzed. Thus, we initially asked the students the questions presented in the following paragraph in quotation marks.

An environmental education team from EMLURB (Company for Urban Maintenance and Cleaning) carried out, in the neighborhoods of the city of Recife, a campaign to raise awareness about urban waste, which consists of about 1% of solid waste containing toxic elements. They showed that among these elements are heavy metals such as cadmium, lead and mercury, components of batteries, which are dangerous to human health and the environment. During the work carried out, they highlighted the current Brazilian legislation (CONAMA, National Council for the Environment, Resolution 401/2008) which regulates the destination of cells and batteries after their energy depletion and determines to manufacturers and/or importers the maximum permitted amount of these metals in each type of cell/battery, but the problem persists. In this contest, answer: What is the relationship between the leakage of substances present in batteries with the nature of heavy metals and damage to human health and the environment? Regarding the disposal site for batteries, which place is more conducive to soil contamination with heavy metals, in the dump or sanitary landfill? Describe (with texts and drawings or construction of mental maps) a possible measure that could contribute to definitively ending environmental pollution by heavy metals highlighted in the text.

The problem situation above has three preliminary questions assigned in Q1, Q2 and Q3.

According to Ferreira et al. (2010) in an investigative proposal, it is necessary to explain the prior knowledge available about the activity, without which it becomes impossible to carry it out. To analyze the responses of Q1, Q2 and Q3 in the problem situation, we used Table 1, based on Lacerda (2008) and Silva et al. (2016); and da Silva et al. (2017). The responses were classified into the following categories: Satisfactory Response (SR); Partially Satisfactory Response (PSR); Unsatisfactory Response (UR) and No Response (NR).

All answers were evaluated by all researchers together in all stages. The responses were read out loud and classified by the reference parameters, confirmed by a consensus of the evaluators.

4.2 Stage 2. Developed hypotheses

Based on the students' previous ideas, their hypotheses will be raised and tested to resolve the issue presented associated with the disposal of batteries in the environment. For this, the students used texts, drawings, mental maps and answered the three preliminary questions.

4.3 Stage 3. A class on electrochemistry

During the class, the researcher talked with the students, encouraging their participation. In this stage, the teacher worked on the electrochemistry content, emphasizing the concepts of the anode, cathode, electrode, electrolyte, reduction, oxidation, reduction and oxidation potential, oxidizing agent, and reducing agent. Then, it
has been approached the contextualization of the chemical matter by exploring natural phenomena such as corrosion, fruit browning, and photosensitive technology in glasses. At the end of the class, students solved exercises individually to consolidate the definitions and concepts of the subjects previously discussed. The objective was to carry out a theoretical approach of the content articulated to the proposed problem.

### 4.4 Stage 4. Developing investigative experimentation activity

At this stage, an investigative experiment was used: the decomposition of batteries in saline solutions, whose objective was to simulate the disposal of batteries in semi-solid media and how electrochemical reactions can impact the balance of the system in which they are inserted. Thus, a general question was presented to students: *What is the best way to collect and recycle batteries and what damage can disposal cause to the environment?*

#### 4.4.1 Experiment investigative: the decomposition of batteries in saline solutions

By conducting this experiment, high school students will observe the accelerated deterioration of batteries in a saline solution. The appearance of colors indicates changes in the pH of the solution and are indicative of chemical reactions. They observed colored chemical reactions identifying Fe$^{2+}$ ions and alkalinity generated by the battery decomposition. The pH of the solution was indicated with sodium ferricyanide and phenolphthalein before and after the addition of the battery.

<table>
<thead>
<tr>
<th>Category</th>
<th>Classification criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 SR</td>
<td>The student, based on scientific knowledge, describes soil contamination caused by spontaneous and non-spontaneous (redox) reactions of the substances present in the Stack.</td>
</tr>
<tr>
<td>SR (exemplo)</td>
<td>“The danger of discarding cells and batteries lies in the fact that, if they are disposed of incorrectly, they can be crushed or burst, letting the toxic liquid leak from their interiors. These substances accumulate in nature because they are not biodegradable, that is, they do not decompose and therefore can contaminate soil and water. In dumps or sanitary landfills, batteries oxidize as a result of exposure to sun and rain. As a result, the casing is ruptured and heavy metals are mixed with the garbage leachate&quot; (Paiva et al., 2018).</td>
</tr>
<tr>
<td>PSR</td>
<td>The student describes soil contamination caused by metallic species but does not relate it to the redox reactions in the environment.</td>
</tr>
<tr>
<td>UR</td>
<td>The student does not make it clear that the contamination is related to the components present in the cells and batteries.</td>
</tr>
<tr>
<td>NR</td>
<td>The student does not fill in the blanks designated in the questionnaire.</td>
</tr>
<tr>
<td>Q2 SR</td>
<td>The student opts for the dump, as this is an open-air location, conducive to soil, water, and air contamination.</td>
</tr>
<tr>
<td>SR (exemplo)</td>
<td>“Over time, contamination of plants, soils, and groundwater inevitably occurs, due to corrosion of the shielding of the pile disposed in so-called controlled landfills and dumps” (Kemerich et al., 2012).</td>
</tr>
<tr>
<td>PSR</td>
<td>The student opts for the landfill instead of the dump, showing that he does not differentiate well between the types of waste treatment that occur in each environment.</td>
</tr>
<tr>
<td>UR</td>
<td>The student does not specify the place where the contamination occurs.</td>
</tr>
<tr>
<td>Q3 SR</td>
<td>The student creates a viable strategy to solve the problem, taking into account the awareness of the population regarding inappropriate disposal.</td>
</tr>
<tr>
<td>SR (exemplo)</td>
<td>“The solution to the problem necessarily involves awareness/education of the population and the application of laws that regulate the manufacture, collection, disposal and technologically sustainable treatment of this type of waste” (Mantuano et al., 2011).</td>
</tr>
<tr>
<td>PSR</td>
<td>The student relies on palliatives as resources to solve the case.</td>
</tr>
<tr>
<td>UR</td>
<td>The student does not propose a coherent strategy to solve the problem.</td>
</tr>
</tbody>
</table>
4.4.2 Materials needed

Agar-Agar medium; sodium chloride; sodium ferricyanide; 1% phenolphthalein alcoholic solution; recycled PET bottles; distilled water; used batteries.

4.4.3 Steps

1) Production of the saline solution: in 200 mL of water, add 2.5 g of agar–agar; 3.0 g of sodium chloride; 0.07 g of sodium ferricyanide, and 1.0 mL of 1% phenolphthalein solution.
2) With a blade, cut the lower part of the PET bottle in a circular shape to produce a ‘pool’ for soaking the batteries. Next, place the battery in the container until it is completely submerged. Follow the experiment and take notes.

The setup of the experiment in a gelatinous/saline medium is shown in Figure 2.

However, to direct the study and enable reflections on broader questions about the implications disposal of batteries, more specific questions were asked:

Q1 When placing the battery in the saline solution, does a reaction occur? How did you come to that conclusion?
Q2 What would be the best way to end environmental pollution caused by improper disposal of batteries?
Q3 When we dispose of batteries in landfills, can they contaminate the environment? Justify your answer.
Q4 Do you think electrolysis occurs in this procedure? Justify your answer.
Q5 What were the products of these reactions at the positive and negative poles? How to explain this phenomenon?
Q6 Observing the experiment, does the oxidation occur in the negative or positive pole? Justify your answer.
Q7 Check the pH of the medium and discuss whether it is as expected. Why is this question important?

Figure 2: Investigative experiment on the decomposition of batteries in saline solutions (The authors, 2023).
In this stage, the teacher–researcher requested that the students should describe how the experiment was done, what results from they obtained, and whether the experiment worked or not. In addition, the students were asked to answer some questions related to the theme proposed in the activity.

4.5 Stage 5. Systematization

In the systematization stage, the students were asked to read the text: A Battery in the Mouth, by Chang (2007). After reading the text, four questions of systematization were proposed, which allowed problematizing the experience analyzed for critical interpretation, were required. They were:

Q1: **Hygiene habits prevent the formation of cavities and, consequently, reduce the use of fillings. By flossing and brushing our teeth, we are removing sugar residues, which can serve as food for cavity-causing bacteria. What is the effect of poor brushing on the bacterial population?**

Q2: **What is the DDP between aluminum and the component with the greatest potential for reducing dental amalgam?**

Q3: **Considering that there is a battery between the gold and each of the metallic alloys presented, which of these batteries would present the highest electromotive force? What would be its value?**

Q4: **Electromotive is the force that tends to establish electric current. Electric current is known to be an ordered flow of electrons migrating from one point to another. Search the internet, dictionaries, or the library of your school or city for the meaning of the word motive and relate it to the definition of electromotive. Justify the existence of electric current.**

After performing the experiment and solving the questions, the students were asked to produce a list with the main electrochemical terms studied during the previous stages of the DS. This material will be covered in the later step for conceptual purposes.

4.6 Stage 6. Communication results

The closure of the DS took place at the results communication stage, where the crucial point was the collective debate between the groups, on all the contents worked on since the first stage. At this stage, the issue of collecting batteries at school and in the neighborhood where they live was also discussed between the groups.

The evaluation criterion at this stage was attitudinal. In this class, participant observation was used as a data collection instrument, which consisted of recording the speeches/participation of students and the production of a list with the main electrochemical terms.

5 Results and discussion

5.1 Problem situation, prior knowledge, and hypothesis

The research question sought to find out the students’ prior knowledge and other conceptual difficulties in the introduction of the content disposal of batteries. The exposed prior knowledge identified by the current study could be described as inside classroom-related (Osman & Sukor, 2013) and these could have been developed during the process of teaching and learning.

Therefore, the results of the pedagogical intervention will be discussed qualitatively and presented in graphs containing the percentages of responses framed in the categories available in Section 1 of the methodology. Figure 3 illustrates the results obtained in the first stages of the study.

According to Figure 3, it is observed that for the first question (Q1 – **What is the relationship between battery leakage and the nature of heavy metals?**) a high percentage of PSR was obtained because only the G5 group
presented a UR. The members mentioned the relationship between the leak and the toxicity of battery components, but none of the groups was able to associate the internal chemical processes with the redox reactions.

The answers to the second question (Q2 – What is the most favorable place for soil contamination with heavy metals?) showed that most groups (G3, G4, G5, and G6) consider the dump as the most favorable location for environmental contamination due to improper disposal of this type of material, thus obtaining a high percentage of SR. One-third of the groups (G1 and G2) indicated UR because they did not specify where the most vulnerable place would be for this event and neither indicated the correct location for the drop.

The third question (Q3 – Suggest actions that can end environmental pollution by heavy metals.) had a high percentage of PSR because only the G1 group stood out with an SR. The groups produced materials containing strategies to remedy the problem available, but only G1 mentioned the importance of environmental education for the population.

Still, in Figure 3, it is observed that the SR is in smaller proportions than the sum of the PSR and UR responses. This indicates that most students did not demonstrate satisfactory knowledge on the topic of the correct disposal of batteries. Demonstrating that they have little prior knowledge of the subject.

During this stage, the students raised some questions of great importance for the development of the research. The first one was: how are batteries able to generate electricity? All groups said that a possible measure to definitively put an end to environmental pollution by heavy metals highlighted in the text would be to dispose of batteries in a suitable container. One of the groups pointed out that this suitable place called “electronic waste” should be installed in urban spaces with greater circulation of people.

5.2 Investigative experimentation

Locatelli (2021) describes myths and concepts that underlie inquiry-based learning, as well as presents an investigative experiment proposal to be used in the classroom.

In this sense, an investigative experiment called “Decomposition of Batteries in Saline Solutions” was developed by the students. During the development of the experiment, the students in some groups did not propose that the formation of products at the poles of the battery came from electrolysis. On the other hand, the phenomenological character of the apparatus (generation of colored substances and gas release) caught the students’ attention and some of them did not know how to associate the electron transfer reactions with the species formed during the event. The system pH was measured before and after the battery submergence, to evidence the formation of ions hydroxyls in one of the poles of the electrolysis (which got pinkish eventually, due to the presence of phenolphthalein in an alkaline medium), but some students understood the role of indicator in
the experiment but are not able to explain the reason behind it. Another difficulty described by the students was
the explanation of the formation of the complex that gives the intense hue of the compound known as Prussian
blue, leading some of them to alternative and conceptually mistaken ideas. These results corroborate what was
described by Ávila and Matos (2017) who proposed to students to carry out qualitative tests for the identification of
iron ions, always emphasizing the color of the product formed.

In sequence, at the end of the experiment, the students answered the seven questions, and the results are
shown in Figure 4.

In Figure 4, it can be seen that in question 1 (Q1 – When placing the battery in the saline solution, does a
reaction occur? How did you come to that conclusion?) 33.33 % of the answers were classified as PSR because
groups G2 and G4 had gaps in their answers sentences and did not mention the formation of hydrogen gas in the
medium, in addition to not making it clear that the phenomenon stemmed from redox.

Regarding question 2, (Q2 – What would be the best way to end environmental pollution caused by improper
disposal of batteries?) 33.33 % of the responses were classified as PSR because groups G3 and G4 only partially
mention the measures necessary to remedy the problem. These groups do not cite the installation of electronic
material collectors, for example, as the other groups mentioned.

When evaluating question 3 (Q3 – When we dispose of batteries in the landfills, can they contaminate the
environment? Justify your answer.) 33.33 % of the groups presented PSR. The similarity between them was that
both groups (G2 and G3) did not relate the internal constitution of cells and batteries with their respective leaks
and toxicities.

The classification as a UR (16.67 %) of G2 in question 4 (Q4 – Do you think electrolysis occurs in this procedure?
Justify your answer.) occurred due to the erroneous correlation of the spontaneity of the reaction, where the
students associated the concept of electrolysis with a spontaneous reaction. Half of the groups (50.00 %) presented
PSR because they did not mention the generation of electric current provided by the battery (electrolysis) at any
time.

In question 5 (Q5 – What were the products of these reactions at the positive and negative poles? How to
explain this phenomenon?) 16.67 % of the groups suggested a UR answer because the students wrote that at the
negative pole, there would be the formation of H⁺ ions, being evaluated as a conceptual error, considering that
hydrogen gas is formed at the cathode.

Regarding question 6 (Q6 – Observing the experiment, does oxidation occur at the negative or positive pole?
Justify your answer.) G3 and G5 (33.33 %) answered wrong because they indicated the negative pole for oxidation.

Regarding question 7 (Q7 – Check the pH of the medium and discuss whether it is as expected. Why is this
question important?) only three groups had access to the measurement of the pH of the medium (G1, G5, and G6),
they used litmus paper to determine the pH value at the positive and negative poles of the pile deposited in the

![Figure 4: Students’ responses during the investigative experiment.](image-url)
water, thus obtaining the results of question 7 only for these three groups. Only one of the analyzed groups presented a satisfactory response because it articulated the impacts generated by sudden changes in pH both in the environment and in the human body.

It is observed in Figure 4 that most of the questions were SR, whereas only two questions (Q4 and Q7) had a higher percentage of PSR and only three questions had UR representing a lower percentage. The plausible explanations for this occurrence in Q4 and Q7 were that students described more visual aspects and did not directly correlate them with chemical reactions; associated damage to the environment mainly by color change and some portrayed the direct variation of the pH of the medium and consequently its impacts. This analysis indicates the success of the use of the apparatus in understanding the analyzed questions and potentiality in the teaching of electrochemistry by DS. Table 2 shows the examples of students’ responses during the investigative experiment.

<table>
<thead>
<tr>
<th>Questão</th>
<th>Exemplo (SR)</th>
<th>Justificativa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>“There is a change of colors, where the positive pole turned blue and the negative pole turned red; you can see this quickly because of the salt that has electrolytes and there was also hydrogen gas formation”.</td>
<td>The group was able to differentiate the poles, in addition to understanding the function of the salt in the medium and they associated the release of hydrogen gas with the bubbles formed.</td>
</tr>
<tr>
<td>Q2</td>
<td>“First of all, awareness and sensitization must be carried out and then battery collectors must be placed so that everyone can have access, especially in places that sell these materials”.</td>
<td>The group described the importance of environmental education, in addition to proposing solutions.</td>
</tr>
<tr>
<td>Q3</td>
<td>“Of course, the wrong disposal can cause serious problems. Over time, these batteries begin to leak liquid materials that contaminate the soil, groundwater, and may reach rivers and lakes. Many of these batteries contain heavy metals such as mercury, nickel, cadmium and lead. These substances are highly toxic and have cumulative effects in the body.”</td>
<td>The group associated the leakage of components from batteries discarded in landfills with the toxicity caused by the heavy metals contained therein.</td>
</tr>
<tr>
<td>Q4</td>
<td>“Yes, it occurs on the outside of the battery where the electrical current from the cell generates a chemical reaction. As phenolphthalein indicates an alkaline medium, there was a reduction in the negative pole which, as it is a non-spontaneous process, differs from the reaction inside the battery.”</td>
<td>It was noted that the group differentiates the chemical reactions that occur internally and externally in the battery.</td>
</tr>
<tr>
<td>Q5</td>
<td>“OH− hydroxyl (alkaline pH) on the negative pole (pink color); the gas released was hydrogen gas. The blue on the positive pole was due to the reaction Fe → Fe²⁺ + 2e⁻”.</td>
<td>It was possible to notice that they identified the products formed in each pole and their contribution to the colors of the experiment.</td>
</tr>
<tr>
<td>Q6</td>
<td>“Oxidation, positive pole, because in electrolysis, which is a non-spontaneous process, the reduction happens to be in the negative pole and oxidation in the positive pole”.</td>
<td>The group distinguished the polarity of cathode and anode in both processes correctly.</td>
</tr>
<tr>
<td>Q7</td>
<td>“We did not expect the pH result to be greater than 7. However, this was observed on the negative pole which changed color to pink and we realized that the medium was becoming alkaline. It is very important to measure the pH of the water, because anyone who drinks water with an acidic or basic pH can have some serious illnesses.”</td>
<td>The group related the pH values with the products generated at the poles and also associated them with possible diseases caused by contaminated water.</td>
</tr>
</tbody>
</table>

5.3 Systematization

The systematization of knowledge is an element that enhances investigative activities, because it allows the socialization of the student’s knowledge, through reflection and investigation. During this time, ideally, all students should be able to understand the concept and scientifically expose the concepts and ideas about the topic...
addressed. According to Carvalho (2013) and Azevedo (2004), the systematization of knowledge is important to prevent a student from leaving class without understanding what was studied. Figure 5 illustrates the results at this stage.

Figure 5 shows that in question 1 (Q1 – What is the effect of poor brushing on the bacterial population?) equivalence was obtained in the categories of answers collected. Taking into account what was requested, some students only described the physical consequences of not brushing their teeth, such as yellowing or bad breath, disconnecting from the real reason for the degradation of amalgams, which would be caused by the great proliferation of bacteria in the mouth.

Data from question 2 (Q2 – What is the DDP between aluminum and the component with the greatest potential for reducing dental amalgam?) indicate a higher percentage of SR, where participants correctly demonstrated all half-reactions and the overall equation, including being successful in calculating the DDP. In the class of PSR, some students correctly proceeded with all the required electrochemical reasoning, however, there were small errors in the mathematical operations. A UR was considered the sentence of a single group that did not formulate the reduction equations and only tried to state in full which species undergo oxidation and reduction.

In question 3 (Q3 – Considering that there is a battery between the gold and each of the metallic alloys presented, which of these batteries would present the highest electromotive force? What would be its value?): the highest percentage of the groups presented RS, where, particularly, the only PSR addressed batteries using silver ions alone, without considering the presence of gold (cathode) in the context described. Only one group did not answer the problem proposed in this question (NR).

In solving question 4 (Q4 – Search the internet, dictionaries, or the library of your school or city for the meaning of the word motive and relate it to the definition of electromotive. Justify the existence of electric current): all participants demonstrated some ease in completing the problem, considering that the glossary (electronic or physical) was of great help in this step. The process of epistemological association about the term “electromotive” was achieved without major impasses and all responses were SR.

Figure 5 shows that, except for Q1, the other questions had a higher percentage of SR, which indicates good student performance. This step was extremely important, as it allowed students to raise questions regarding electrochemical terms, manage to select relevant information from the text and relate the reading to the different moments of the experimental activity.
5.4 Communication of results

Communication of results is the time to report the results, difficulties, and limitations of the investigation to the scientific community or society. Figure 6 illustrates the results of the analysis of the list produced with the main electrochemical terms studied during the previous stages of the DS.

The inappropriate electrochemical terms encompass other content taught during DS but they are not electrochemical terms such as environmental impact; nature of the battery; ionic species and concepts related to electricity.

In Figure 6, it can be seen that G3 was the one that suggested the most terms (48), even having the highest percentage of inappropriate electrochemical terms. G1 stands out for reaching the highest number of appropriate electrochemical terms (23), even having approximately 44% of invalid responses in the evaluation. It is noted that among all the groups, only G6 had less expressiveness (11 terms), but it was not considered as a great discrepancy from the others, considering that its percentage of appropriate electrochemical terms exceeded 80%.

It is believed that the expressive values in inappropriate electrochemical terms were due to competition between groups to be able to suggest more expressions in this activity.

The most repeated appropriate electrochemical terms were: oxidation/reduction; anode/cathode; reducing/oxidizing agent and batteries. In the first highlighted terms above, the percentage of terms defined correctly was 100%. Only G1 presented an SR for the battery expression. In this last instrument, it is noted that G1 was the only one that presented coherent definitions in all seven main terms highlighted for the activity proposed in the communication. These data indicate a good level of electrochemistry learning during DS.

At this stage, the issue of collecting batteries at school and in the neighborhood where they live was also discussed between the groups. The students proposed to identify and publicize the battery collection stations close to the school, such as shops, pharmacies, and supermarkets, to realize the extension of environmental awareness in the community. To finalize the research, they built a battery collection container that was installed in the school.

Just like Lacerda et al. (2012) who studied the importance of agriculture in the production of food for our survival, this search also showed the importance of approach to scientific content in a teaching perspective that includes problems that portray themes of society.

The DS had some limitations due to the number of groups worked on simultaneously, so it was necessary the help of interns to record and take notes on the interventions, in addition to the participation of other researchers.

![Figure 6: Students' responses in the results communication stage.](image)
6 Conclusions

The developed DS focused on studies of electrochemistry, specifically the disposal of batteries, an attempt was made to boost the development and the learning of the content. The results showed that DS allowed the contextualization and development of actions and skills aimed at carrying out tasks in the school context.

Students showed interest and motivation throughout this DS. There were strong student–student and student–teacher interactions demonstrated in the resolution of the steps proposed in the SD. The researchers attribute this to the fact that the issue of battery disposal is present in their lives.

In the first stage of the DS most students did not demonstrate satisfactory knowledge on the topic of the correct disposal of batteries. Demonstrating that they have little prior knowledge of the subject. The situation problem led the students to investigate and create hypotheses to answer the three preliminary questions.

Numerous possibilities of activities could be done in the classroom from an investigative perspective, but an experiment on the “Decomposition of Batteries in Saline Solutions” was realized in the present study with favorable results for the student’s chemistry learning, with the use of simple materials and without the need for laboratory use.

It was observed in this investigative experiment that most of the questions obtained satisfactory response associated damage to the environment mainly indicated by color change due to variation of the pH of the medium and consequently its impacts. This analysis indicates the success of the use of the apparatus in understanding the analyzed questions and potentiality in the teaching of electrochemistry by DS.

In the systematization of the knowledge stage, most questions had a higher percentage of satisfactory response, which indicates good student performance. This step was extremely important, as it allowed students to raise questions regarding electrochemical terms, manage to select relevant information from the text and relate the reading to the different moments of the investigative experiment.

In the last stage of the DS, communicating the results, it was observed that all groups cited and correctly defined the main electrochemical terms studied. This indicates that the students had a good level of electrochemistry learning during the DS.

Students’ comments reinforced the need to approach scientific contents in a teaching perspective that contemplates problems that portray themes of society. The students proposed to identify and publicize the battery collection stations close to the school and built a battery collection container that was installed in the school.

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