Educación Química

Problem-solving methodology from an STS perspective: a proposal for the teaching of electrochemistry

Metodología de resolución de problemas desde una perspectiva CTS: una propuesta para la enseñanza de la electroquímica

Bruna de Brito de Souza Canali, Marisa Longo, Daniel das Chagas de Azevedo Ribeiro y Camila Greff Passos[1]

Resumen

Este trabajo investiga las contribuciones de la metodología de resolución de problemas (RS) a la enseñanza de la electroquímica desde una perspectiva de CTS (ciencia, tecnología y sociedad). La investigación se llevó a cabo con 82 estudiantes de cuatro clases del tercer año de la escuela secundaria, en una escuela pública estatal en la región metropolitana de Porto Alegre (estado de Rio Grande do Sul, Brasil). Se utilizaron dos problemas, ambos cumpliendo con las características de un problema efectivo. Los datos de investigación se obtuvieron a partir de las soluciones propuestas por los estudiantes, así como de los registros en el diario de campo del investigador. Estos documentos fueron examinados mediante análisis de contenido, basado en categorías definidas a priori. El análisis de los resultados mostró que la metodología de resolución de problemas contribuyó al aprendizaje de los estudiantes y permitió la asociación entre los contenidos de electroquímica y cuestiones tecnológicas, sociales y ambientales.

Palabras clave: enseñanza de la electroquímica; educación química; resolución de problemas.

Abstract

This work investigates the contributions of the problem-solving (PS) methodology to the teaching of electrochemistry from an STS (science, technology, and society) perspective. The research was undertaken with 82 students from four classes of the 3rd year of high school, at a state public school in the metropolitan region of Porto Alegre (Rio Grande do Sul state, Brazil). Two problems were used, both complying with the characteristics of an effective problem. The research data were obtained from the problem solutions proposed by the students, as well as from the records in the field diary of the researcher. These documents were examined by content analysis, based on categories defined a priori. Analysis of the results showed that the PS methodology contributed to the learning of the students and enabled association between the electrochemistry contents and technological, social, and environmental issues.

Keywords: electrochemistry teaching; chemistry education; problem-solving.

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[1] Universidade Federal do Rio Grande do Sul. Programa de Pós-Graduação em Química. Porto Alegre, RS, Brasil.

Introduction

The teaching and learning of electrochemistry can present great difficulty for both teachers and students. Some electrochemistry concepts are hard to understand, with the students being required to develop models and use scientific language, which can lead to confusion (Karpudewan and Huri, 2023; Meloni, 2016). Difficulties may be related to the identification of reactions in the electrochemical cell, the way that the flow of electrons occurs, and the terminologies used, such as electrolyte, anode, cathode, and bridge or saline solution in the case of batteries (Ferreira et al., 2021; Niaz and Chacón, 2003).

Besides the difficulties in understanding due to the complexity of the content, the exclusive use of traditional teaching methods may be unable to relate chemistry contents to the daily lives of the students (Meloni, 2016; Ferreira et al., 2021). The science isolated from social, ethical, and political issues can hinder the development of critical thinking in students (Ribeiro et al., 2020; Ribeiro et al., 2022). To address this, it may be more appropriate to employ active teaching and learning methods. One way to improve contextualization, as well as to encourage critical and active attributes in the students, is by application of the problem-solving (PS) methodology (Cowden and Santiago, 2016; Martínez and Martínez Aznar, 2014; Domin and Bodner, 2012). Here, it is considered that contextualization enables the construction of meanings, going beyond merely providing examples (Wartha and Alário, 2005; Wartha et al., 2013).

One of the ways to provide contextualization considers the science, technology, and society (STS) concept as a guiding principle that favors the integration of scientific and technological knowledge with ethical, political, historical, and social issues (Livramento et al., 2021; Silva and Marcondes, 2015). Therefore, the present work investigates the contributions of the PS methodology to the teaching of electrochemistry, from an STS perspective, in third year classes at a state high school in the metropolitan region of Porto Alegre (Rio Grande do Sul state, Brazil).

Theoretical basis

The teaching of chemistry is often performed according to a traditional curriculum that prioritizes only certain conceptual aspects of chemistry, where concepts and definitions may be used in a mechanical way by teachers and, consequently, by students (Machado et al., 2000). In the chemistry learning process, students should be introduced to the different levels of representation of matter, such that they pass through three stages, namely understanding of the macroscopic, microscopic, and symbolic, enabling the student to observe a phenomenon, understand it, and represent it in a symbolic way (Karpudewan and Huri, 2023; Niaz and Chacón, 2003).

The teaching of chemistry generally prioritizes aspects that involve memory, so the students may have the impression that the science of chemistry is disconnected from reality, since the way in which concepts are presented requires memorization, rather than the establishment of connections and relationships with daily life (Meloni, 2016; Ferreira et al., 2021; Machado et al., 2000). Learning difficulties especially common among chemistry students are those related to abstract concepts, use of scientific language, construction of mental models, and understanding of chemical bonds and reactions (Wartha and Alário, 2005; Wartha et al., 2013).

In the teaching of electrochemistry, redox reactions can be a challenge for both teachers and students, since they are complex and require the understanding of a set of concepts, such as anode, cathode, reduction, oxidation, and electron transfer (Karpudewan and Huri, 2023; Meloni, 2016). Among specific difficulties in learning electrochemistry, Niaz and Chacón (2003) reported that the greatest problems were in identifying where the reaction occurs in the electrochemical cell, how the flow of electrons occurs, and the nature of an electrolyte, in addition to the terminology employed. Barreto et al., (2017) highlighted difficulties related to the understanding of oxidation and reduction reactions, the phenomenon of corrosion, and the way that electron transfer generates electric current. The existence of these difficulties necessitates the use of methodologies and strategies that can assist in making associations between phenomena and theory. Such strategies should be designed so that students can learn in a way that is integrated and contextualized (Ferreira et al., 2021; Niaz and Chacón, 2003).

The main characteristic of the PS methodology is that the students are actively involved in their acquisition of contextualized knowledge (Cowden and Santiago, 2016; Martínez and Martínez Aznar, 2014). This methodology, which was first used in science education in the 1990s, is derived from the problem-based learning (PBL) method (Domin and Bodner, 2012; Lima et al., 2017). It aims at the learning of scientific concepts by employing problems whose resolution requires the use of specific procedures (García et al., 2020; Sevian et al., 2015).

A problem may be defined as a situation that an individual or a group wants or needs to resolve, for which there is no fast and direct path leading to the solution (Ribeiro et al., 2020; Cowden and Santiago, 2016). As pointed out by Ribeiro et al., (2020) teaching how to solve problems not only involves providing students with methods and resolution strategies, but also creating in them the ability to view the learning process as a problem to which the answer must be found. Hence, the main objective of proposing problems to students is to incentivize them to acquire the habit of proposing and solving problems, as a way of learning (Ribeiro et al., 2022; Domin and Bodner, 2012).

In the PS method, the students play an active investigative role, while the teacher guides the study. The knowledge derived from a problem is acquired as the students observe, elaborate hypotheses, consult sources of information, design a solution to the problem, and implement the solution (Martínez and Martínez Aznar, 2014; García et al., 2020).

The use and implementation of the PS methodology involves several steps, (Aznar and Nieto, 2009) as follows:

1. Qualitative analysis of the problem: Analysis of the statements, the identification of possible alternative conceptions by the students, and analysis of the need to elaborate a theoretical basis to assist in the proposal of hypotheses.

2. Proposal of hypotheses: The students suggest hypotheses important for interpretation of the results obtained.

3. Elaboration of resolution strategies: The students produce a work plan with the procedures needed to solve the problem.

4. Resolution of the problem: Each group should preferably provide a different solution to the proposed problem. The students should be encouraged to explain

the strategies used in each step of elaborating their solution, with the aim of identifying errors.

5. Analysis of results: All the results should be evaluated, enabling identification of specific difficulties of the students.

Therefore, problem-solving involves a process of reflection, with decision-making based on a sequence of steps performed during elaboration of the solution, which distinguishes this process from a simple exercise. In the latter case, the solution is obtained by means of a set of mechanisms that involve standard patterns of thought, without any requirement for critical reflection.

Ribeiro et al., (2020) considered, from a theoretical perspective, that an effective problem should provide four important features: contextualization, critical reflection, motivation, and stimulation of research.

The contextualization of a proposed problem enables it to be related to daily life, consequently increasing the involvement and motivation of the student, who can perceive the relation between theory and practice (Wartha et al., 2013).

An effective problem should provoke a critical reflection that can lead the student to adopting a particular social or political position. When a problem is elaborated in a way that promotes critical reflection, the students can acquire the ability to solve situations that are more challenging, improving their creativity and critical awareness when faced with problems (Ribeiro et al., 2020).

An effective problem is one that motivates the learner to provide a solution, since motivation is an inherent human condition leading to the performance or continuation of a task. The motivation to solve a problem is not only related to internal factors of the individual, but also to the conditions under which the problem will be solved, such as the learning environment and the guidance provided by the teacher. Motivated students show better performance, because they feel involved with the proposed problem (Authors, 2020).

Finally, an effective problem should favor research. To solve a problem, the students must elaborate suitable hypotheses and procedures, otherwise the problem will not be solved (Sevian et al., 2015; Cowden and Santiago, 2016). In preparing these procedures and hypotheses, the student must also establish what is to be investigated. In establishing their methods, the students make decisions and are ultimately able to obtain appropriate solutions to the proposed problem (Ribeiro et al., 2020).

Methodology

This research was performed in an educational environment, using qualitative research methodology, reflecting a type of dialogue between the investigators and the subjects under investigation (Denzin and Lincoln, 2005). An analysis is presented of an experience using the PS methodology in a high school, contextualizing topics related to the teaching of electrochemistry. The study was carried out with four third-year classes (last year of high school), totaling 82 students, in the evening period at a state public school in the city of Cachoeirinha, in the metropolitan region of Porto Alegre (Rio Grande do Sul state, Brazil). The data for the research were obtained from the problem solutions proposed by the students, in addition to the records of the teacher. A free and informed consent term was applied, in order to be able to use the data collected in this research.

Evaluation of the problem solutions was based on an interpretative analysis of the results using a priori content analysis categories (Bardin, 2011). The content analysis technique consists of three stages: a pre-analysis, in which the analysis is organized by means of the elaboration of hypotheses and indicators that provide a basis for interpretation of the data; exploration of the material, involving encoding of the data; and treatment and interpretation of the results, with the data being categorized using the indicators obtained previously (Bardin, 2011).

A description of the didactic activities is provided in Table 1. The stages suggested by Aznar and Nieto (2009) for implementation of the PS methodology were developed during classes 5 and 6, with a total of 4 hours for each class. The PS activities were undertaken by 82 students, who were organized into 23 groups. For consideration of the responses, the groups were randomly identified by labeling them from 1 to 23.

Table 1. Summary of activities undertaken.

Class	Objectives	Methodology	Didactic resources
1	Introduce the concepts of redox reactions. Enable understanding of the nature of a redox reaction. Develop ideas and reflections about the guiding question and identify the factors responsible for the rusting and corrosion process.	Guiding question: Why are iron gates and fences usually painted with oil paint? Use of an explanatory diagram, functioning as follows: It starts with the establishment of a question. Having found the causes or answers to the question, further questions are then asked about how or why they occurred. This sequence encourages teamwork and helps in the development of ideas and reflections.	Dynamic elaboration of the explanatory diagram, in order to organize the knowledge of the students.
2	Encourage reflection on the changes needed to preserve the planet, considering social, economic, and environmental aspects.	Visit to the exhibition of sculptures inspired by the 17 sustainable development goals (SDGs), which can be found on the website: https://brasil.un.org/pt-br/sdgs The exhibition was installed at the gasometer plant in the city of Porto Alegre. The students undertook filming at the exhibition site, in order to prepare documentaries. Each documentary should highlight aspects of the objective of the group and indicate an intervention to address the identified problem.	Visit to the SDGs exhibition. Production of a documentary with a proposed intervention.

3	Identify what constitutes oxidizing and reducing substances. Observe an electrochemical reaction and propose hypotheses to explain it.	Practical class held in groups, with the students observing and writing down their conclusions about the activity.	Experiment: "Vitamin C as a reducing agent - interaction with iodine." Preparation of a report about the practical activity. Exercises concerning NOx calculation.
4	Development of autonomy and reflection in the students by their production of a documentary and creation of a thematic room.	Presentation of the project concerning the 17 SDGs, using a thematic room and the documentary produced by the students, with an explanation of the objective and a proposed intervention.	Construction of the thematic room using recyclable materials. Presentation of the documentaries produced by the students.
5	Analyze and discuss the different uses and types of cells and batteries. Reflect on consumerism and obsolescence, especially regarding electronic equipment. Understand the difference between cell and battery, identifying the types of reactions in these devices.	The constitution of cells and batteries is discussed, based on the guiding question: "What is needed for a cell or battery to function?" Construction of a cell in a demonstrative experiment employing simple materials (small cans). Use of slides to complement the explanation of different types of cells and batteries and their applications. Use of a video to explain the concept of planned obsolescence and to reflect on consumer culture. Guidance for the group elaboration of solutions to problems.	Demonstrative experiment: Cell made of cans. Slides about the types and applications of cells and batteries. Use of a video about programmed obsolescence: https://youtu.be/dxbD0pUzjP0 Solving of problems elaborated by the teacher.
6	Reflect on the disposal of cells and batteries, and the associated environmental impacts. Evaluate alternatives to cells and batteries.	Debate about the proposed problem solution, analyzing social, economic, technological, and environmental aspects. Completion of an evaluation questionnaire.	Presentation of the solutions elaborated by the students, using different presentation resources. Evaluation questionnaire.

The analysis of the written productions and presentations of the 23 groups was carried out interpretively using the instrument utilized in a previous study by Sales and Santos (2022). These researchers adapted the rubrics developed by Toma et al., (2017) for the context of the study on didactic materials developed by teachers in training, in order to analyze the resolutions of school cases and problems, as performed in this research. This instrument is divided into four a priori categories: identification and definition of the problem; bibliographic research; use of chemical concepts in the solutions; and presentation of the solutions. The scale is shown in Table 2.

Categories	A	B	C	D
1. Identification and definition of the problem. Raising questions. Organization of the group to perform the work.	Identifies the problem. Presents a delimitation of the topic. The group shows organization to perform the work.	Identifies the problem. Presents a delimitation of the topic. The group shows partial organization to perform the work.	Identifies the problem. Does not present a delimitation of the topic. The group shows little organization to perform the work.	Does not identify the problem and does not delimit the topic. The group shows no organization to perform the work.
2. Bibliographic research.	Uses one or more bibliographic sources. The topic is discussed.	Uses only one bibliographic source. The topic is discussed superficially.	Uses only one bibliographic source. The topic is not discussed.	No use of bibliographic sources is presented.
3. Use of chemical concepts in solving the problem.	Presents a satisfactory relation among electrochemical reactions, the disposal of cells and batteries, and fuel cells.	Presents a superficial relation among electrochemical reactions, the disposal of cells and batteries, and fuel cells.	Presents a minimum relation among electrochemical reactions, the disposal of cells and batteries, and fuel cells.	Presents no relation among electrochemical reactions, the disposal of cells and batteries, and fuel cells.
4. Solutions presented.	Presents an effective solution. The group presents the solution creatively, using arguments to support it.	Presents an effective solution. The group presents the solution with a degree of creativity, using some arguments to support it.	Presents a marginally effective solution. The group presents the solution with little creativity, without sufficient arguments to support it.	Does not present an effective solution. The group does not present the solution creatively and does not provide arguments to support it.

Table 2. Scale used to classify the solutions of the problems.

Results and discussion

The problems and their solutions

Elaboration of the problems was according to the main characteristics of an effective problem, as indicated by Ribeiro et al., (2020) These characteristics consider the contextualization of the problem, critical reflection, motivation, and the possibilities for investigation and decision-making.

Contextualization of the problems endeavored to use information well known by the students, highlighting aspects that could encourage the process of critical reflection. Motivation of the students to address a particular problem was assisted by including the context of a daily activity or imagining a future professional situation. The proposed problems were designed to enable investigation and research by the students. Decision-making ability was encouraged, enabling the students to adopt positions regarding their solutions.

The problems elaborated were consistent with the guidelines for competences and abilities established by the BNCC, where one of the specific competences in the area of Natural Sciences and Technologies is stated as follows: "Analysis of natural phenomena and technological processes, based on the interactions and relationships between matter and energy, in order to propose individual and collective actions that can improve production processes, reduce socio-environmental impacts, and improve conditions for life at the local, regional, and global levels" (Brazil, 2018).

Table 3 presents the problems elaborated, together with the characteristics of an effective problem highlighted by Ribeiro et al., (2020). The problems were validated by researchers from the chemistry teaching area, who made suggestions that were incorporated.

Table 3. Problems elaborated and proposed solutions.

Problem I: In recent decades, there has been a significant increase in the consumption of portable electronic devices such as toys, cell phones, computers, cameras, electric tools, and medical devices, among others. Consequently, concomitantly with this growth, there has been an increased demand for batteries. In Brazil alone, in 2019, more than 2 million tons of electronic waste were discarded, including devices containing heavy metals and other toxic materials harmful to the environment. Hence, the increase in consumption is reflected in the increase in disposal. Imagine the following situation: During the organization of some boxes that were stored in a cupboard in your home, you noticed the presence of several electronic devices, including some loose batteries. You decide to dispose of these objects, since they have not been used for a long time. What would be the consequences if you disposed of these objects in the normal trash? Investigate the different disposal options and discuss their advantages and disadvantages, considering economic, environmental, and social factors. Then decide which would be your selected disposal method. Legend: Contextualization; Critical reflection; Motivation; Investigation possibility.
Problem II: Given the need to increase the durability and the energy efficiency of cells and batteries, there is a search for new technologies. In addition to energy efficiency, such alternatives should also have lower environmental impacts. An example is the fuel cell. You work for an energy supplier and your role is to undertake research and find the best options available on the market to meet the requirements of your company, which is considering possible investment in fuel cell research. In your research, you identify fuel cells as a highly efficient option. Make a report for your company, highlighting the economic, environmental, and social advantages and disadvantages of this type of energy. Also, briefly describe the operating principles of this type of device. Legend: Contextualization; Critical reflection; Motivation; Investigation possibility.

Tables 4 and 5 show the results for the evaluation, based on the scale presented in the Methodology (Table 2), of the written productions and presentations of the problem solutions provided by the 23 groups. Table 6 shows a summary of the theoretical strategies developed by the students for the two problems.

Table 4. Evaluation of the proposed solutions to Problem I.

Category	*A*	*B*	*C*	*D*
1	21 groups	2 groups		
2	13 groups	2 groups		8 groups
3	22 groups	1 group		
4	11 groups	12 groups		

Table 5. Evaluation of the proposed solutions to Problem II

Category	*A*	*B*	*C*	*D*
1	21 groups	2 groups		
2	13 groups	2 groups		8 groups
3	22 groups	1 group		
4	7 groups	9 groups	7 groups	

Table 6. Strategies used by the students to solve the problems.

Theoretical strategies	
Pr I	Recycling projects. Reduced consumption. Awareness. Divulgation. Donation as an alternative to disposal.
Pr II	Presentation of definitions, description of the process of obtaining energy from fuel cells. Identification of environmental and social advantages. Identification of environmental impacts.

Together with the strategies used by students to solve problems, the inclusion of socio-environmental contents in the teaching of chemistry has been discussed by educators and researchers, focusing on structured associations among the STS components and the strengthening of communication among students, enabling them to express and share points of view. In the STS approach, topics to be contextualized should allow the students to reflect on social and environmental issues, giving them the opportunity to become committed and, if possible, enabling them to change their own reality (Livramento et al., 2021; Silva and Marcondes, 2015).

In the case of category 1, evaluating the ability of the students to delimit the topics of the problems and demonstrate organization for the elaboration of solutions, 21 groups were able to satisfactorily identify the two problems, while 2 groups showed organizational difficulties.

For category 2, concerning the use of bibliographic references and discussion about the topic, all the groups used research sources, but some groups did not present the sources as requested. In addition, some groups had difficulty in discussing the problems presented.

For category 3, regarding the relation between electrochemical reactions and the topics of the problems, the students from 22 groups were able to satisfactorily relate the concepts learned in electrochemistry classes to both proposed problems, as can be seen by the following examples:

> "Hydrogen is separated, by an anode, into an electron and a proton, and the electron passes through the circuit, electrifying something. The proton crosses the electrolyte and arrives, together with the electron, at the pole where oxygen is released and their combination forms water." (Group 4, class 305, authors' emphasis).

> "The fuel cell is a device used for the conversion of electrochemical energy. It can convert hydrogen and oxygen into electricity." (Group 1, class 306, authors' emphasis).

> "Both equipment and batteries contain substances that, if sent to landfill in trash, can significantly harm the environment." (Group 4, class 304, authors' emphasis).

Finally, in the case of the solutions presented for the problems (category 4), the responses for problem I showed greater creativity and critical reflection in the arguments, as shown by the following examples:

> "Projects for the recycling and disposal of electronic waste deserve greater attention by society, since the amount of waste produced is huge, increasingly so, given the accelerated growth of new technologies. There must be widespread divulgation, since few people are aware of their existence, as in the case of the project cited. Therefore, every individual should endeavor to make others aware of the importance of these practices for positively affecting all aspects of our society." (Group 2, class 305).

This is an interesting proposal, highlighting the need for awareness in obtaining a solution. Although only having access to information (being aware of the problem) does not necessarily change attitudes, the proposal of the group is that there should be a collective effort to make the problem known to everyone, in this way motivating change (Santos et al., 2013). In another proposed solution, group 3, from class 303, suggested that donation could be a good option:

> "Donation is a way to dispose of electronic waste".

Similarly, group 4, also from class 303, suggested the need to reconsider notions of consumption. This demonstrated that in addition to satisfactorily delimiting the topic, the students were able to perceive the relation with planned obsolescence, which was an issue also addressed in class:

> "The big problem is the exaggerated consumption characteristic of the capitalist system. We believe that in order to help in addressing this problem, we could reduce unnecessary purchases and donate items that we no longer use."

Some of the groups greatly identified with problem I, as shown by their locating appropriate local disposal sites:

> "How should items be disposed of correctly? It is a good idea to search the internet for specific collection points for electronic waste and batteries, such as the nearby trade recycling facility in Cachoeirinha." (Authors' emphasis)

For category 4 of problem II, 9 groups showed low creativity in their solutions, while 6 groups did not show creativity or the use of good arguments in their solutions. This could indicate that problem II was not viewed as a real problem by a majority (15) of the groups, with its solution taking more of the form of an academic exercise. Problem II had the characteristics of a more closed problem, which may have limited the creativity of the students and led to the lack of identification of a problem to be solved. Ribeiro et al., (2021) reported that more open-ended problems present the student with something unknown, resulting in the need to develop strategies, hypotheses, and critical capacity, in order to find a solution. On the other hand, problems that are more closed, where there are more instructions and information, may not be considered as problems by the students, but rather as only exercises. In a future application of the problems, the groups should receive the problems separately and in sequence, in order to diversify and deepen discussions on related topics. Previous studies point to the potential of using sequential problems for conceptual and procedural deepening of the topic (Goi and Santos, 2009), and they can serve as useful indicators of the degree of conceptual understanding that the individual brings to the problem-solving event (Domin and Bodner, 2012).

Nonetheless, it could be considered that the two problems awakened awareness in the students concerning the disposal of cells and batteries, alternative sources of energy, and the causes and consequences of related socio-environmental problems. According to Santos et al., (2013) "In becoming aware, the individual needs to perform an action, whether material or otherwise, and be capable of explaining it, because knowing how to explain or justify such an action demonstrates the capacity for conceptual construction".

Analysis of the Problem-Solving methodology with a STS emphasis

Analysis of whether the PS methodology was consistent with the STS approach employed the instrument adapted from Silva and Marcondes (2015) shown in Figure 1. Adaptations of this nature were carried out in previous studies (Livramento et al., 2021).

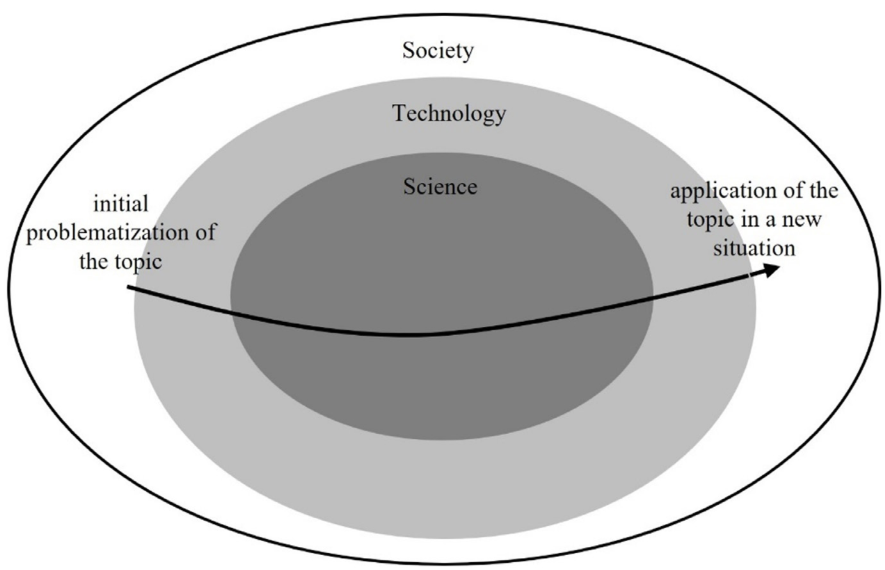

Figure 1. Conceptual structure of the problems developed. Adapted by Silva and Marcondes (2015).

This instrument was adapted considering the following aspects: analysis of the initial problematization regarding the chosen topic; the interface among the areas of science, technology, and society (STS) regarding the topic; the relations among the specific knowledge of chemistry related to this project, electrochemistry, and problematization, for finally, application for the topic in a new situation. It is pertinent to highlight that a adaptation to the context of this research, as the analyzes presented by Silva and Marcondes (2015) were carried out on teaching units produced by teachers in training. The analysis instrument used for the proposed problems is shown in Figure 2.

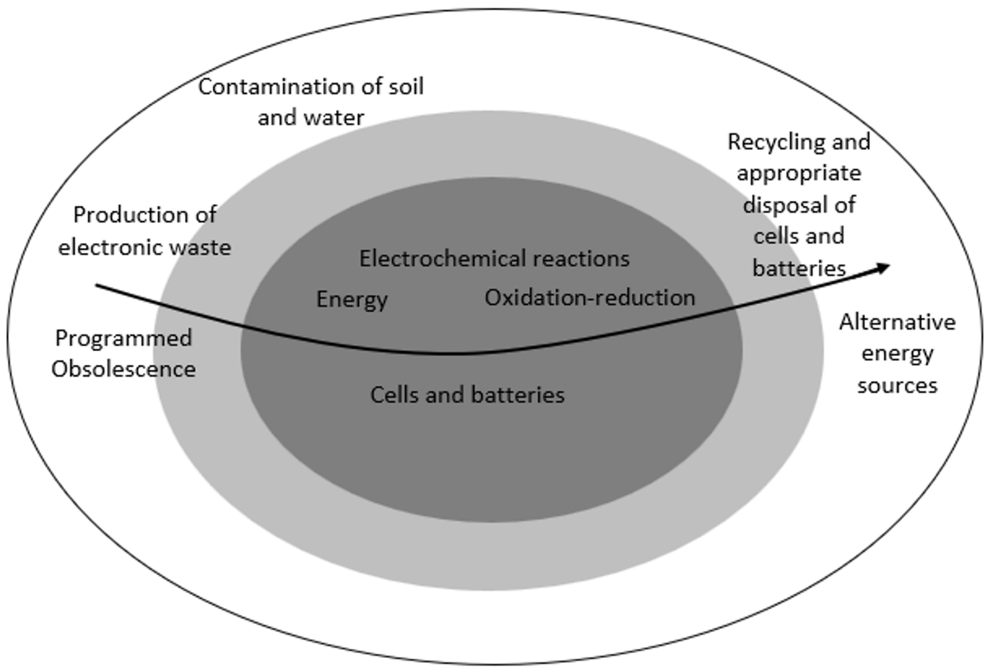

Figure 2. Conceptual structure of the developed problems.

The intention in the elaborated problems (Table 3) was to employ content related to soil and water contamination, together with recycling, to develop a socio-environmental discussion (initial problematization of the topic). Concerning technological aspects, an analysis of the production of electronic waste and its relation to planned obsolescence was proposed. The elaborated problems and the materials worked on in class clearly evidenced that aspects related to the consumption of electronic devices and the consequent generation of electronic waste were within the areas of technology and society. In the case of the science area, the proposed problems and the classes considered concepts related to energy and electrochemical redox reactions, as well as concepts regarding cells and batteries (the interface among the areas of science, technology, and society). Finally, the problems addressed issues related to waste disposal and the use of alternative energy sources with lower environmental impacts (application for the topic in a new situation).

In this way, the elaboration of the problems was directed towards an educational process with emphasis on the STS approach, since this could favor the integration of scientific and technological knowledge with socio-environmental issues. The procedure led to a teaching and learning process that problematized the contradictions of contemporary models of development and society, based on discussion and investigation of the factors causing such contradictions, their consequences, and the co-responsibility of all (Livramento et al., 2021; Silva and Marcondes, 2015).

The data obtained in this study showed that it successfully achieved the main objective, namely to identify contributions of the PS methodology for the teaching of electrochemistry from an STS perspective. This could be seen from the awareness demonstrated by the students (Santos et al., 2013) in elaborating their solutions, especially in the case of problem I, with the discussion of electrochemistry concepts being associated with the socio-environmental, technological, and political-economic contexts related to the disposal options for electronic waste and batteries, as well as to alternative energy sources that have lower environmental impacts.

Conclusion

This work reports on the elaboration and use of two problems that complied with the characteristics of an effective problem, for use in the teaching of electrochemistry to 3rd year high school students. The focus was on presenting problems from an STS perspective, employing situations that could stimulate debate in the classroom concerning the associated social, technological, environmental, and economic issues.

The two elaborated problems had different focuses, with problem I simulating an everyday situation, while problem II had an industrial context. The difference between these two problems was significantly reflected in the ability of the students to identify with the problems. Although the students showed a certain difficulty in discussing the problems, the solutions presented by the 23 groups showed that they were able to use and articulate the concepts introduced in previous theoretical classes, enabling them to provide adequate solutions to the proposed problems.

Overall, the results demonstrated the suitability of the PS methodology, in association with the guiding principles of STS, for the teaching and learning process analyzed in this study. This was because the problems were organized in such a way as to meet the requirements for an effective problem, with the students being incentivized to undertake research, work in groups, and elaborate arguments for solving the problems.

In future application of the PS methodology, it would be desirable to reorganize the distribution of the problems to the different groups. The groups should receive problems separately and in sequence, in order to expand the discussions about the related issues.

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