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Exploring a Contextualized STEM Integration in Chemistry Education Laboratory: Insights from Pre-Service Teacher Training

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ABSTRACT

Empowering students with a robust Science, Technology, Engineering, and Mathematics (STEM) education, while equipping their teachers with comprehensive training, fosters critical thinking and problem-solving skills, which are important aspects of innovation, social progress, and advancement. The main objective of this study is to investigate how a STEM-lab activity - an experimental chemistry laboratory activity integrated with Arduino prototyping - implemented within a teacher education program can promote the development of professional knowledge that enables the development of activities aligned with the STEM approach among pre-service teachers. Twenty Portuguese pre-service physics and chemistry teachers participated in the study. Pre- and post-activity tests, incorporating closed and open-ended questions, were used to assess participants' perceptions. Data analysis included quantitative assessment of conceptual gains and qualitative content analysis of reflective responses. The results suggest that the activity fosters a reflective process among pre-service chemistry teachers, enabling them to integrate STEM components with a socio-scientific contextual approach and encouraging critical consideration of adapting STEM activities for greater applicability and effectiveness in secondary education. While this approach significantly enhances pedagogical effectiveness, challenges persist in identifying aspects related to engineering and using Arduino prototyping.

Keywords: STEM, pre-service teachers, chemistry education, Arduino prototyping

INTRODUCTION

A STEM education perspective is considered essential for preparing students with the skills necessary to address complex and transdisciplinary challenges in sectors such as health, climate change, energy, and transportation (English, 2017; Paiva et al., 2017).

According to Bybee (2013), STEM integration can be disciplinary, multidisciplinary, interdisciplinary, or transdisciplinary. This study adopts an interdisciplinary approach, as it intentionally connects chemistry, mathematics, engineering, and technology (Arduino) through a context-based experimental activity focused on water quality. While each discipline retains some boundaries, they are purposefully linked to foster meaningful learning and real-world problem-solving (Bybee, 2013).

Originally conceived to prepare students for the dynamic socio-technological scenarios of actual society, STEM education now incorporates a pedagogical dimension that prioritizes real-world problem-solving and experiential learning. STEM education is supported by pedagogical approaches and strategies like the Science, Technology, Society, and Environment (STSE) approach, inquiry-based learning, and experimental and investigative practices, among others (Coskun Karabulut et al., 2023; Bicer et al., 2020; García & Espinosa, 2020; Karamustafaoğlu & Pektaş, 2023; Morais et al., 2021; Morais & Araújo, 2023; Schmidt & Fulton, 2016). Implementing problem-based learning within STSE and STEM projects encourages a reflective, creative, integrative, and intellectually enriching teaching paradigm, contrasting with traditional concept transmission models (Boy, 2013; Santos, 2012; August, 2023; Olalowo, 2020; Shaughnessy, 2013).

A comprehensive literature review identifies two primary approaches to defining STEM education objectives (Perignat & Katz-Buonincontro, 2019). The first approach focuses on enhancing learning within STEM fields, particularly by engaging minority and female students, sparking interest in STEM careers, and developing essential skills for these careers. The second emphasizes developing general skills like creativity, problem-solving, and interdisciplinary knowledge transfer, advocating for exploratory and experiential learning methods (Bush et al., 2016; Gettings, 2016; Kant et al., 2018; Yıldız & Ecevit, 2024). These approaches involve integrating specific conceptual domains and a range of skills. It is crucial to respect the epistemological nuances of each discipline to develop educational strategies that effectively articulate these disciplines, considering their specificities (Tang & Williams, 2019).

In chemistry science, knowledge structures rely on experimentation and various representations to foster understanding, aiming to develop theories from observable phenomena (Gilbert & Treagust, 2009; Johnstone, 1991; Spita et al, 2024; Taber, 2013). Mathematics emphasizes a logical-deductive approach using abstract representations, while engineering and technology focus on practical skills within design contexts to address specific problems and societal needs (Grewe, 2025; Shaughnessy, 2013; Spyropoulou & Kameas, 2023). Understanding these specificities is important to developing multidisciplinary programs that significantly enhance students' educational outcomes and career readiness by developing crucial skills across disciplines (McGoldrick et al., 2013).

Another important aspect is the potential of pedagogical approaches. STSE and strategies such as experimental activities and inquiry-based learning can support the development of STEM education. Tsang (2021) demonstrates how integrating STEM perspectives and STSE approaches effectively merges content and language with a focus on sustainability and problem-solving. This integration enriches educational methodologies by fostering skills in data automation, collaborative interpretation, effective communication, and interdisciplinary knowledge.

Considering the aspects presented, STEM education involves an articulation between the disciplines involved in an interdisciplinary perspective. We are guided by this perspective of developing and integrating knowledge from the different STEM disciplines, considering epistemological, psychological, and didactic aspects (Kelley & Knowles, 2016; Ortiz-Revilla et al., 2022, Hussim et al, 2024).

In the epistemological axis, it is considered that empirical problems are problems related to science present in everyday life that require an explanation. Although there are epistemological differences in the type of problems solved in science, engineering, mathematics, and technology, it is recognized that there are common points between scientific problems and problems defined in other disciplines. The psychological axis considers that a set of situations fosters the construction of knowledge in a STEM proposal, creating a connection between prior knowledge, new knowledge, and representations. These first two axes connect to the didactic axis through different approaches (investigative, experimental, socio-scientific, for example) that aim to overcome epistemological obstacles and mistakes (Kelley & Knowles, 2016).

In the sense of developing and integrating knowledge from the different STEM disciplines, considering epistemological, psychological, and didactic aspects (Ortiz-Revilla et al., 2022), we align this theoretical framework with the contextualization perspective through the STSE approach, characterized as a social mobilization of broad discussion about science and technology, their purposes and implications in society. Therefore, it is a proposal that emerges from social issues due to a change in the conception about the nature of scientific knowledge and its role in society, working with the search for solutions to problems associated with scientific knowledge involved in the school context (Durbin, 1991; Pedretti & Nazir, 2011). STSE approach aims to use students' real-world experiences to allow them to explore the interfaces between science and the social world, to enable them to understand social and scientific topics and issues, formulate their visions and points of view on these issues, recognize the social, political and economic forces that influence scientific and technological activities, make informed and responsible decisions, and act in their environment (Hodson, 2003, 2020).

Therefore, we consider a training proposal that considers a context from the STSE perspective for the development of knowledge of STEM disciplines associated with the aspect of integration, and the development of professional knowledge involves the mobilization of different conceptual domains. For proposals that involve integration, such as STEM and STSE, it is necessary to know whether students regularly study in these areas.

In this sense, integrating investigative experimental activities with technological tools, engineering principles, and investigative strategies in Chemistry Education could enhance collaborative learning through STEM tasks and group discussions deepens students' understanding of chemical phenomena and enhances their communicative and cooperative skills (Leopold & Smith, 2019; Thompson & Soyibo, 2002).

Recent initiatives integrate traditional chemistry experiments with modern Arduino-based sensors, enriching studies of thermodynamics, atmospheric pollution, and chemical titrations (de Vera et al., 2022; Famularo et al., 2016; Fleischer et al., 2024; Gomes et al., 2020; Morais & Araújo, 2023; Pino et al., 2019; Rodriguez-Vasquez et al., 2020). Integrating these activities with investigative strategies like Predict-Observe-Explain (POE) (White & Gunstone, 2014) improves student learning in chemistry (Ayvacı, 2013; Güngör Seyhan & Eyceyurt Türk, 2023; Hilario, 2015) and the effectiveness of STEM implementation.

Challenges to implementing STEM proposals include time constraints, increased workload, and lack of support, which hinder content integration and collaboration (Land, 2013; Park et al., 2016). There is a need for reevaluated professional development models to meet educational, cultural, and socio-economic needs. Integrating chemical content with STEM practices in teacher training significantly increases receptivity, enhancing future educators' digital, pedagogical, and technological skills (Deniş Çeliker, 2020; Margot & Kettler, 2019; Song & Zhou, 2021).

Participatory activities in multidisciplinary domains within teacher training curricula have illustrated possibilities for action with STEM proposals. Emphasizing STEM disciplines integration, especially engineering in online settings, enhances learning, creativity, and incorporating multiple subjects in future chemistry teachers' activities (Ambrož et al., 2023; Aydin-Gunbatar et al., 2020). While STEM education could integrate conceptual development and skill acquisition, there is a need for training practices that address its varied domains comprehensively.

The main objective of this study is to investigate how a STEM-lab activity - an experimental chemistry laboratory activity integrated with Arduino prototyping – implemented within a teacher education program can promote the development of professional knowledge that enables the development of activities aligned with the STEM approach among pre-service teachers (PST).

To achieve this end, the following three specific objectives have been outlined:

1. To investigate which contents of the STEM disciplines incorporated into the STEM-lab activity are identified by PST during their reflection on the conducted activity.

2. To explore whether PST recognizes preferred contexts for exploring the proposed STEM-lab activity and whether they propose new contexts that could substantiate the activity for high school students.

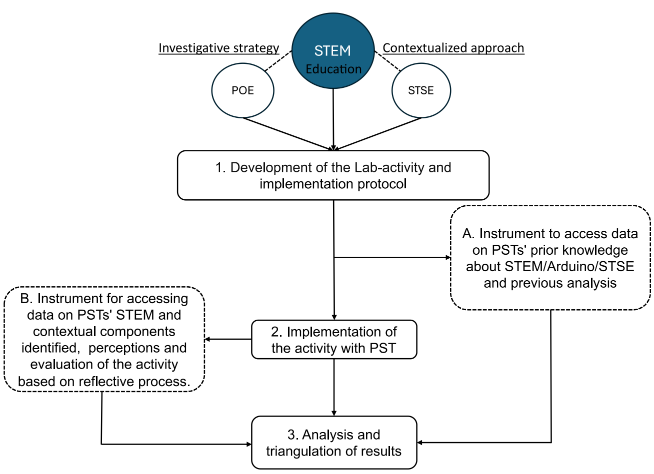
3. To identify the potentialities and challenges pointed out by the PST regarding the STEM lab activity developed, focusing on adapting the activity for high school students.

METHODOLOGY

Setting and Participants

The study used a convenience sample of 20 voluntary chemistry teachers in initial training enrolled in the Master's program in Physics and Chemistry Teaching at the University of Porto, Portugal. The group included 7 males and 13 females, aged 21 to 55. Participants were informed about the study's content, confidentiality, duration, and their right to withdraw at any time, providing written informed consent. The investigation's methodological structure involved developing and implementing a STEM-lab activity using the investigative strategy POE. Data was collected before and during the implementation phase for subsequent analysis. Figure 1 outlines the methodological path.

Figure 1. *Stages of research implementation, data collection, and analysis.*



Development of the STEM-lab activity and the implementation protocol

In developing the didactic proposal, we integrated theoretical components of STEM education, contextual integration, and an investigative pedagogical approach to engage pre-service chemistry teachers. The focus is on a laboratory activity covering electrochemistry, specifically concentration cells. In the Portuguese high school chemistry curriculum, the content of electrochemistry appears in the 11th and 12th grades However, the activity was designed to be implemented in the 12th grade, where the content of electrochemical cells is explored in more depth. Electrochemistry was chosen due to its instructional challenges and conceptual complexity, often hindering learning (Greenbowe, 1997; Rahayu et al., 2022). This topic is particularly relevant because of its application in electrical energy production, related to batteries and biological systems' regulatory mechanisms, aligning with the Sustainable Development Goals (United Nations, 2023).

The researchers developed an experimental system, including a concentration cell setup linked with an Arduino-based low-cost electronic system for automated data acquisition (Morais et al., 2024). This setup measured the electrical conductivity and potential differences of solutions, displaying the results on an electronic screen. The experiment integrates mathematics, technology, and engineering through specific equations like the Nernst equation for electrochemical potential and conductivity calibration, and the use of Arduino and a Spreadsheet. The didactic protocol was available in Supplementary Online Material.

The implementation was designed for a 12th-grade classroom, using a POE strategy to foster a predictive and investigative learning environment. The activity begins with initial inference, followed by data collection and measurements, engaging participants in applying their electrochemistry and mathematics knowledge to analyze and explain the observed phenomena, thereby linking prior knowledge with new insights (Hilario, 2015).

This strategy aims to engage PST participants in a cyclical process of prediction, observation, and reinterpretation, fostering reflective learning throughout the STEM-lab activity that brings different content from STEM disciplines into the activity in the context of students' daily lives. With this, it is expected that PST will be able to recognize and apply these concepts in their future activities.

Implementation of the STEM-lab activity, data collection instruments

For data collection, we integrated a series of instruments. Initially, participants completed a pre-test featuring six true/false questions about electrochemistry and nine Likert scale questions (1 - Strongly Disagree; 2 – Disagree; 3 – Neutral; 4 – Agree; 5 - Strongly Agree) assessing views on STEM education, STSE approach, and Arduino knowledge.

The pre- and post-test instruments were submitted to **content validation** by three experts in science education with experience in STEM teaching and teacher training. These experts evaluated the items for clarity, relevance, and alignment with the learning goals of the STEM-lab activity. Based on their feedback, minor revisions were made before the instruments were applied.

The pre-test was administered around 15 days before the activity so that there would be a gap between the pre- and post-test, as the latter was completed on the day of the activity. It is assumed that the PST have some knowledge of aspects of electrochemistry since they have already received instruction on the subject in their undergraduate course. However, since the topic carries difficulties and alternative conceptions, these could be found in the answers. At the end of the pre-test, the PST were informed that in approximately 15 days, they would carry out an experimental activity related to the test content without, however, receiving any further information about the specifics of the experimental activity itself.

The post-test followed the activity, evaluating the activity's feasibility and STEM skills with ten additional items. We maintained the true-false items, and there are three more Likert items, added to the nine from the pre-test, in assessing views on STEM education, STSE approach, and Arduino knowledge. These three groups of items are considered Question 1 in the post-test (See Supplementary Online Material). Additionally, there are five more open questions to assess the educational perspective, contextual application, and prospective challenges of implementing the STEM-lab activity at the high school level, as described in the following:

Question 2: Identify the knowledge and content areas associated with the different disciplines within a STEM-lab activity.

Question 3: Reflect on the integration of Science, Technology, Society, and Environment (STSE) areas in the activity. Two contexts were proposed for participants to identify the STSE areas (See Supplementary Online Material).

Question 4: Assess the activity in terms of what could start doing, stop doing, continue doing, do more, and do less.

Question 5: Describe any new insights, skills, or understandings gained from participating in the activity

Question 6: Describe the difficulties experienced in carrying out the activity.

Analysis and triangulation of results

The analysis was divided into three parts to organize the results and their discussion. Table 1 lists the questions, the form of analysis, and the specific objectives to which they are associated.

In Part 1, the six true/false items related to electrochemistry were analyzed using Hake's normalized gain for comparison. This involved calculating the difference in mean scores before and after the activity, standardized against the pre-test scores (Hake, 1998). The Likert scale questionnaire was analyzed using descriptive statistics by constructing histograms that make it possible to access a view of the initial and final responses and, subsequently, discuss these findings based on the analysis of the content of the written responses.

For Part 2, the PST responses to questions 2 to 6 were analyzed through content analysis (Bardin, 1977) to identify distinct elements in these two parts and establish textures in data triangulation. The content analysis was performed by considering the reading and re-reading of the PST's responses and the establishment of emerging categories. That is, for each of the STEM disciplines and each of the STSE areas, we established associated subcategories based on the frequency of occurrence of analysis units. The analysis units are characterized by fragments of the associated responses that represent the meaning of a given category. By analyzing questions 2 and 3, we established the contents in STEM disciplines and STSE areas to recognize how the PST identifies and integrates the different STEM components. In the same way, in part 3 (questions 4 to 6), we adopted emerging categories to identify which pedagogical and technical aspects potentially limit the STEM-lab activity.

Table 1. *Questions of questionnaires, data analysis, and research objective associated*

Questions	Data analysis	Research objective associated
Likert-scale and true and false questionnaire (pre and post-test)	Part 1. Score accounting and correlation with content analysis	Specific Objectives 1 and 3
2 and 3	Part 2. Content Analysis with categories associated to STEM and STSE areas	Specific Objectives 1 and 2
4 to 6	Part 3. Content Analysis with categories associated with possibilities, difficulties, and action to adopt the activity for high school scenarios	Specific Objectives 1 and 3

RESULTS AND DISCUSSION

Part 1 - Pre and post-test questionnaires about electrochemical content (Likert-scale and true and false questions)

For the first part, data about electrochemical content from the pre and post-test questionnaires were analyzed, and the results are expressed in Figures 2 and 3. Comparing the ratings obtained by the participants on the set of six true-false items in the pre and post-questionnaires (Figure 2), Hake´s normalized gain (HNG) was calculated - and is equal to $\frac{post-pre}{100-pre}$ (Hake, 1998) -, and also the average gain of the 20 participants (Figure 3). We analyze the data using the rating considered by Hake (1998): High-gain if HNG≥70%, Low-gain if HNG <30% and Medium-gain if 30%≤HNG<70%. Six participants maintained their results between the pre-and post-test, and 14 improved in the post-test. For example, participants 7, 16, 18 and 19 (Figure 3) had a score of 50% in the pre-test, and obtained a HNG between the pre and post-test of 0%, 33%, 67% and 100% respectively. The average Hake's normalized gain of 51% corresponds to a medium gain (Hake, 1998).

In the pre-test, more than half of the participants scored below 50%. This can be explained by the fact that although the activity was applied to chemistry teachers in their initial training, they were not informed of the chemical content that would be used in the activity beforehand. The low performance in the pre-test, where more than half of the PST scored below 50%, may indicate insufficient prior knowledge of electrochemical concepts. This is consistent with findings from the literature that highlight the abstract and multifaceted nature of electrochemistry, which is often addressed in a fragmented or purely theoretical manner in initial teacher training.

Figure 2. *Percentage Hake´s normalized gain between pre- and post-test by participant for the true-false item set*

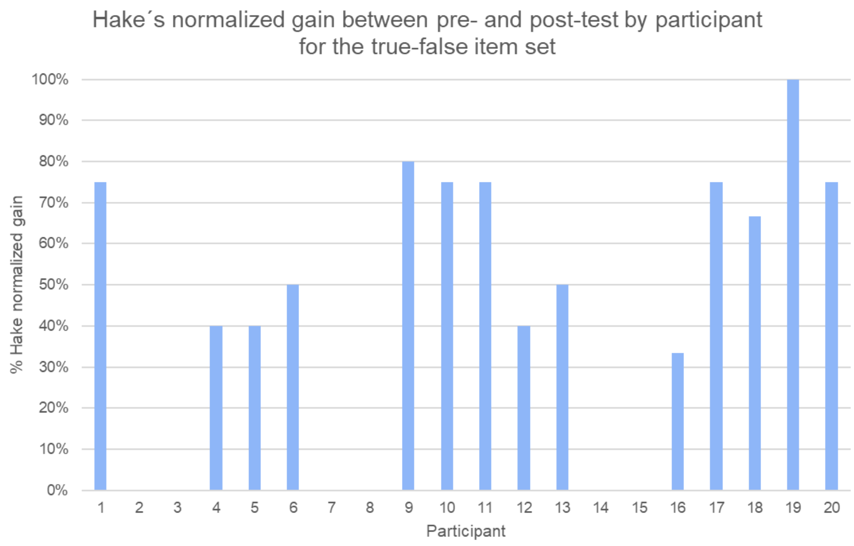
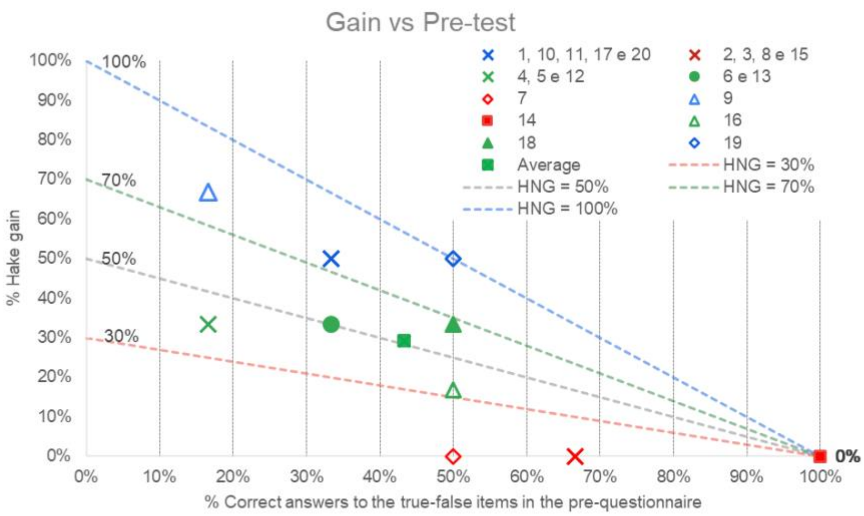
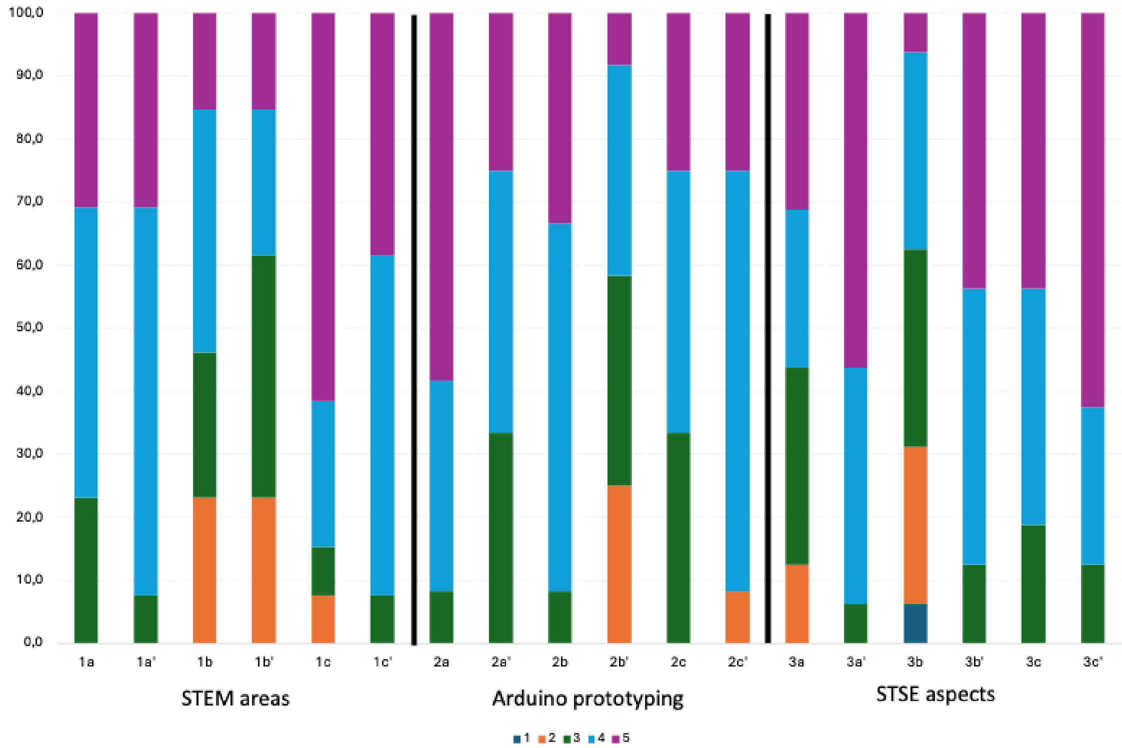


Figure 3. *Percentage gain vs percentage pre-test score on the true-false items about electrochemical cells knowledge for 20 participants*



Responses on knowledge and motivations about STEM and STSE were presented and compared in Figure 4. The pre-test items are represented by the number followed by the letter (1a, 1b, 1c, 2a, 2b, 2c, etc.) and the post-test items are indicated by the number, letter, and apostrophe (1a', 1b', 1c', 2a', 2b', 2c', etc.), using a five-point scale (1… 2…3… 4… and 5…). In the graph, we seek to observe an overview of how the responses varied. Items numbered 1 refer to STEM aspects; items numbered 2 refer to Arduino prototyping aspects; items numbered 3 refer to STSE aspects. The questions are presented in the Supplementary Online Material.

Figure 4. *Percentage of responses about STEM areas, Arduino prototyping, and STSE in pre and post-tests*



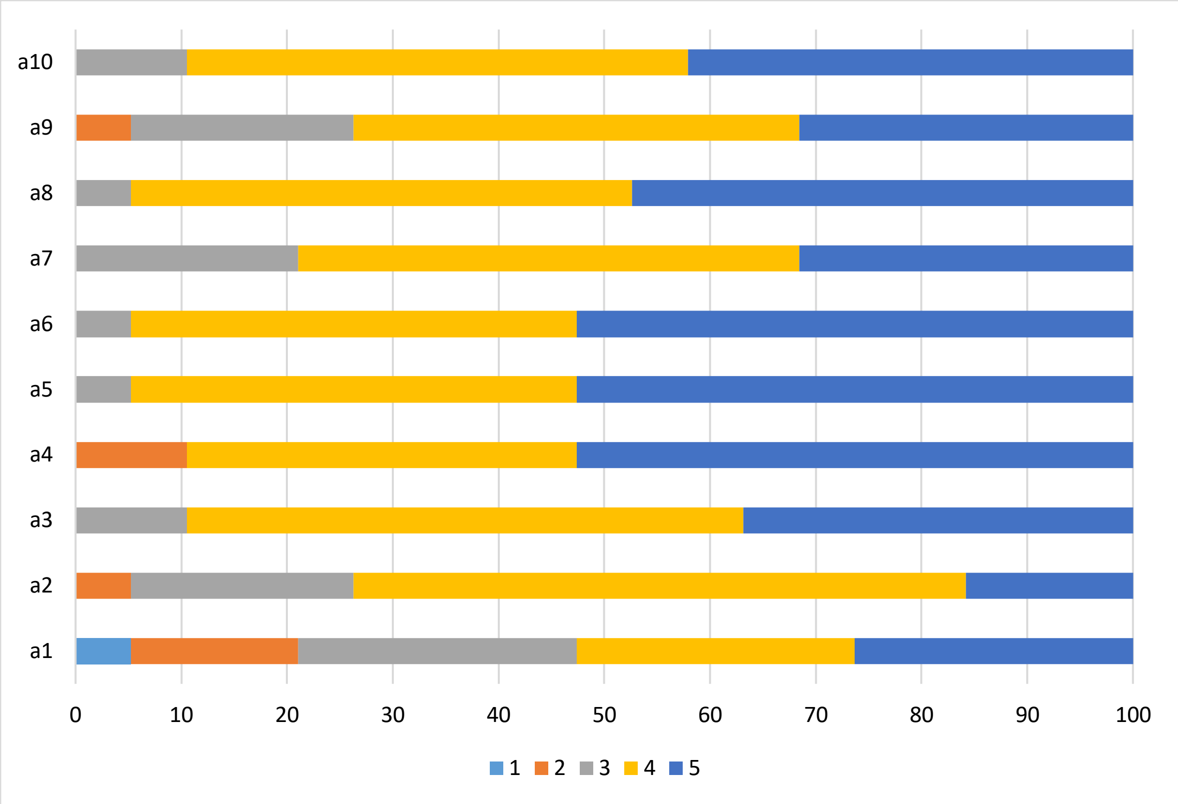
This preliminary data did not find substantial variations in the responses to most of the statements. However, some initial observations could be made. Regarding STEM and STSE, it was possible to note an increase in all items, particularly in statements 1c and 1c' (*I believe that the use of a STEM approach has the potential to foster students' learning and interest in Chemistry*) and in all items for STSE. On the other hand, questions related to Arduino show a decrease in responses to 2a and 2b questions (motivation and facility to integrate Arduino, respectively). This fact may be related to how the activity was developed. The PST did not build an assembly. The concentration cell developed involves a system with a set of electronic components, which may give an initial impression of complexity and also distance the topics of electronics from the teacher training scenario. The literature highlights the challenge that teachers face in integrating technological aspects and mastering electronic circuits, in addition to the typical content of the training course, it presents a challenge (Dökme & Koyunlu Ünlü, 2023; Shahidullah et., 2022; Jho et al., 2016).

In the proposal, the didactic planning directly involved the search for articulation between the different STEM disciplines through problematization with a focus on the STSE approach, an important aspect of learning about STEM education (Kelley & Knowles, 2016). On the other hand, the experimental proposal was presented ready-made and was only manipulated by the PST. Since the set appeared to be complex in terms of connections, electronic components, and software, it may have led the PST to perceive its implementation as more challenging.

In this sense, we questioned the PST about the ease of use and also the possibilities that the activity brings. Figure 5 shows the participants' assessments of the feasibility of carrying out the activity for teachers and students and the types of learning they considered possible. The questions are presented in the Supplementary Online Material.

Participants positively evaluated the activity for work with STEM skills. However, the teacher's difficulties with preparation, particularly with technology and Arduino prototyping, highlight areas for future training. Questions a1 and a2 are related to activity preparation and ease for students to work on. We noticed that these points are those with the least positive evaluations, being related to aspects already mentioned, such as the structure of the experiment. However, the adequacy of the context and content (a3 and a4) and the possibility of working with STEM skills (a5 to a10), except for creativity, which we consider coherent since there is no assembly by the students in this proposal.

Figure 5. *Percentage of responses about ease of implementation and STEM skills.*



Part 2. Content analysis with categories associated with STEM and STSE areas

In the second analysis phase, participants' recognition of STEM and STSE contents was examined. Table 2 illustrates their responses to post-test question 2, associating the laboratory activity with STEM contents. The categorization resulted in 87 exclusive analysis units, with percentages identified for each category and subcategory, showing participants' understanding of the activity's STEM aspects.

It is noted that the components of science and technology are more identified while aspects of mathematics and engineering are mentioned less by participants. The chemical content is very evident in the proposal, as is the entire technology-oriented scheme, with the circuit and Arduino prototyping being visible and tangible to the participants. The experimental design, associated with engineering, may not have been mentioned by the participants since they were not responsible for structuring and assembling the experiment or thinking about the algorithmic logic necessary to build the code, an aspect related to mathematics. These issues will be discussed later.

Table 3 depicts the organization of participants' answers to question 3 (part 2), wherein they were prompted to correlate the laboratory task they conducted with STSE areas. The categorization of responses resulted in 80 analysis units, and the percentages for each category and subcategory were identified. As the same as question 2, the analysis units are exclusive.

This distinction is significant because STEM education, although focused on developing skills and abilities, can become restricted to specific domains if worked in isolation. Integrating STEM with STSE approaches can help participants integrate these concepts more contextually (Pedretti & Nazir, 2011; Tsang, 2021). For example, discussions about electrical energy production for automobiles connected technical concepts with social and environmental aspects, the impact of pollutants, new materials, etc.

Engineering had the fewest units of analysis, mainly focusing on engineering literacy related to experimental design and resource application, resulting in only six units (SC7). This aligns with the literature noting that areas like engineering are less familiar to teachers (Aydin, Oztay, & Ekiz, 2021; Shernoff, Sinha, Bressler, & Ginsburg, 2017; Siew, Amir, & Chong, 2015). Participants did not engage in building or conceptualizing the system; they merely used it, suggesting future interventions could involve co-creating activities with PST to develop these components.

Table 3. *Categorization of answers to post-test questionnaire question 3 (part 2) considering the STSE areas. Total of units of analysis n=80*

STSE		
Area / Category	Subcategory	Examples of units of analysis
Science (27,5%)	SC10. (15%) Electrochemistry topics;	Concentration cells; potential energy generation; Chemical reaction (electrochemistry).
	SC11. (10%) New materials and sustainable energy development;	Materials that may constitute the battery. Develop less aggressive techniques for searching for the metals that make up batteries.
	SC12. (2,5%) Human Physiology;	Ionic concentration. Cardiac cell and external and internal fluids.
Technology (23,7%)	SC13. (13,8%) Production of batteries / new materials for electric cars;	Methods to produce more efficient batteries; automobiles with electric motor technology.
	SC14. (6,3%) Energy matrix, pollution and fuels;	Less polluting techniques for the production of electrical energy; Energy production without the use of fossil fuels.
	SC15. Others (3,8%) - Heart cell, Arduino, Concentration cell components;	Heart cells; Arduino.
Society (22,5%)	SC16. (12,5%) Sustainability and quality of life;	Develop strategies for a more sustainable world; Analysis of the consequences for public and economic health.
	SC17. (7,5%) Economic aspects;	Discussion of the economic viability of replacing the energy matrix; Cost of the solution compared to the cost of batteries.
	SC18. (2,5%) Human physiology;	Human physiology; consequences of K+ ion imbalances in the human body.
Environment (26,3%)	SC19. (20%) Fossil fuels, batteries and environmental pollution;	Reaction products (which can be pollutants) and replacement of fossil fuels; reduction of waste and fossil fuels.
	SC20. (6,3%) Impact of battery production.	Environmental impact of battery production; production of concentration cells and production of fossil fuels.

Two ready-made contexts were presented to pre-service chemistry teachers: Context A, related to energy production for electric cars and climate summits (like COP 28), and Context B, related to ionic regulation in the human body by concentration differences (see Supplementary Online Material). The goal was to identify whether participants could recognize concepts from different areas within these contexts. Participants identified elements in context A but had difficulty considering other situations, possibly due to their lack of involvement in the activity's idealization and experimental construction. The STSE approach is based on proposals in which the problematization should precede conceptual development, enabling a critical articulation between scientific content and context (Santos & Auler, 2019).

Participants were also asked to choose a context for implementing the activity with future high school students, providing a rationale and suggesting an alternative context. Seventeen of the 20 participants chose context A, citing the STSE perspective, current relevance, and ease of contextualization involving chemical content. The three who chose context B focused on working with human physiology.

The analysis of the responses illustrates participants' ability to link theoretical concepts with practical applications in real-world contexts, highlighting the effectiveness of integrating STEM and STSE approaches in enhancing their teaching methodologies. As examples of arguments cited by participants, we highlight:

> Because it allows, [...] science (reaction) used in a technology (batteries), which is at the service of society (cars) and is being used to improve environmental pollution issues.
> Addresses scientific content linked to environmental, technological, and social issues (the latter resulting from climate change and the impact on public health, unlike example B, which focuses only on biological processes in the human body. So, example A is best suited to an STSE approach.

Regarding the proposal of a new possible context for working with the activity, we received responses from five participants: three related to the topic of battery production in systems with greater energy efficiency and involving environmental concerns, and the other two related to water pollution. Some of the descriptions of the participants are illustrated below:

> Construction of batteries for energy situations/developing countries. Enhance STSE, identical to the level of science and technology as in the previous point. Socially for catastrophe situations and solutions for society. Environmentally, it is more positive and slows down the destruction of batteries and their manufacturing as their lifespan can be increased or alternative.
> Study of the concentration of metal ions in water (rivers, lakes, etc.) in agricultural production using the concept of concentration cell (or electrochemistry) to test the presence of some metals (example: chromium).

Part 3. Content Analysis with categories associated with possibilities, difficulties and actions to adapt the activity for high school scenarios

After answering questions 2 and 3, participants carried out the process of reflection on the lab-activity, mediated by questions 4 to 6. When analyzing the answers to these questions, we sought to identify which areas and aspects are highlighted as prospects for improving the activity. In this sense, the pedagogical approach is the focus of analysis and procedural aspects of implementing the activity. As mentioned in our methodology, we analyzed the responses based on content analysis considering emerging categories and subcategories, described in Table 4.

In total, the responses were identified and divided into 67 exclusive units of analysis. Table 6 illustrates the results of this categorization with the percentages analysis units for each category and subcategory.

We can highlight some significant points. In terms of possibilities observed by participants, it is evident that the development of concepts specific to electrochemistry is remarkable, being the second subcategory with the highest number of analysis units (SC22). This aspect aligns with what the literature reports about this specific content. For both teachers and students, electrochemistry is a domain that is difficult to understand as it involves, in addition to a range of prior knowledge, an integration between macro, micro, and symbolic domains of knowledge and the experimental activities involving the subject are complex to be implemented (Karpudewan & Daman Huri, 2023; Tsaparlis, 2019). In this sense, it is understood that the experimental approach developed and articulated with technological devices can contribute to the conceptual training of future teachers.

Considering the pedagogical aspect, subcategory SC21 reports the investigative aspects as enhancing skills such as creativity, investigative competence, and critical thinking. We can correlate this data with the responses for items in Figure 5. The answers obtained by the analysis units agree with the answers given by the participants about STEM skills, which show most answers above score 4. These answers indicate that the experiment proposal, based on investigative teaching, was recognized as positive by the participants, providing them with a different approach from the traditional one and with the potential for developing target skills from STEM education. These results align with studies that propose teacher training projects from a STEM education, which recognize that participation in projects contributes to the building positive perceptions and knowledge about strategies for implementation of STEM practices (Aydin-Gunbatar et al., 2020; Deniş Çeliker, 2020; Shernoff et al., 2017; Fernández et al, 2024; Ali et al, 2024).

In table 4 it is noted that the participants consider the activity appropriate to the school context but consider it a particular difficulty in preparing the proposal and in terms of execution by the students. When correlating these responses with categories 2 and 3, we noticed that the central adaptations suggested by the participants, which are aspects that they consider difficult, are related to greater clarity of the investigative proposal and work with electronic devices and prototyping with Arduino.

Table 4. *Categories and subcategories emerging from the answers to questions 4, 5 and 6. Total of units of analysis n=67*

Category	Subcategory	Examples of units of analysis
C1. Potential of activities in relation to the investigative process and the concepts of electrochemistry. (41,8%)	SC21. Pedagogical aspects (16,4%)	Maintaining the various hypotheses until discovery promotes creativity and interest; The fact that the activity was divided into parts, the clues make us think and we feel like authentic detectives; The activity can be used to provoke investigation into the subject (theme); The problem-solving structure of trying to figure out what's in the "mystery box"; How to stimulate students' creativity, interest, critical spirit; I learned another motivating way to teach.
	SC22. Electrochemistry concepts (25,4%)	I promoted knowledge of electrochemistry; About the application of concentration cells. Above all, remember how an electrochemical cell works; I learned that we could carry out oxidation-reduction reactions with the same metal in solutions with the aqueous metal but different concentrations; How to assemble electrochemical cells and compare theoretical values with experimental values of potential difference generated by the cell. Characterization of a concentration cell (anode vs. cathode, oxidation vs. reduction); I remembered concepts that were already "forgotten" and learned how to carry out an electrochemical activity using Arduino; Calculate the d.d.p. using the Nernst equation; How to prepare a salt bridge.
C2. Adaptation of the activity to teaching and learning contexts. (29,8%)	SC23. Contextual aspects (14,9%)	Approach to the theoretical context; Create a story; Initial contextualization of the activity; Apply in a real situation where the concentration cell is used; Contextualize with a mechanism that students are familiar with or highlight a STSE approach in the protocol.
	SC24. Specific content aspects (14,9%)	A comparison with electrochemical cells and in terms of reduction potential and ease of construction; Use with different metals; Have more concentration cells, with different electrodes, for example; It is possible to carry out a qualitative analysis of copper solutions by visualizing the color of each one and relating this visual aspect to the concentration.
C3. Technical adaptations and activity execution protocol. (28,4%)	Without subcategories (28,4%)	There are times when there are no observations to make. Make it clear that if there are observations, record them; I think the hypothesis part should be better explained; A more complete reflection of each stage, perhaps adding some information about the role of the recorded quantities, as many students are unaware of their role; A brief introduction to the construction of the electrical circuit; Use instruments other than the Arduino to measure the potential difference, such as a voltmeter and confirm the values; Explain how to set up the experiment with both the Arduino and the chemistry component.

Concerning the investigative nature, there must be clarity in objectives and methodology in proposals that seek to move away from transmissive-receptive teaching. In this sense, the evaluation by the PST provides both the reflective process aimed at professional development for acting as future teachers. It provides feedback on adapting the training proposal developed and reported in this study. Studies involving the experience of PST in activities, in the role of students, with a focus on recognizing potentialities and difficulties associated with the implementation of these proposals, have shown that such practice contributes to the development of professional knowledge (Girotto Júnior et al., 2019; Widyasari et al., 2022). In our investigation, it is possible to identify the recognition of the potential of the activity and, simultaneously, the critical analysis of it by the participants.

Regarding the difficulties associated with Arduino, knowledge about electronics and programming is undoubtedly not part of the areas covered in initial teacher training. Therefore, prototyping and programming were expected to be highlighted as limitations. However, it should be noted that, for this activity, conceptual domains on such topics were not required.

Regarding contextual and content adjustments (category 2), participants highlight that carrying out measurements with other electrochemical systems would be interesting, which makes us recognize that the proposal is appropriate and can be applied to more situations. We particularly highlight contextual adequacy. Even with fewer analysis units, students highlight that the activity requires contextualization. The practice that was inserted in the context of this research did not present contexts or problematizations for the laboratory activity, one of the objectives being that the participants proposed such contexts. The answers illustrate that the participants recognize the need to "create a story" or to propose an "initial contextualization of the activity" and to "application in a real situation in which the concentration cell is used". This recognition is important, and we believe it aligns with our objectives regarding recognizing components from STEM education and the STSE approach.

Data Triangulation

Considering the data set and the discussions, we seek to weave a connection to illustrate the possible integrations identified between STEM education, the STSE approach, and the pedagogical domains.

From the PST responses, it is noted that the identified STEM contents are presented within a more specific domain for each area, such as specific concepts of electrochemistry (science), electronics (technology); experimental design (engineering), and the use of equations and formulas (mathematics). Still, internally, science, technology, and mathematics present common topics, with engineering being integrated only with the area of technology. On the other hand, the STSE areas are cited for the most comprehensive and contextual aspects, such as sustainable development and energy matrix (science), new products and materials (technology), sustainability and quality of life (society), and fossil fuels and pollution (environment). For the STSE areas, it is noted that the themes raised by the participants are, in part, common to all, showing a strong integration between the areas.

The more specific or contextual character is directly related to the development of the areas. STEM education tends to consider the specific concepts of each area, considering their epistemologies and subsequently combining them in the development of an integrative discipline. In this way, the conceptual domains identified are expected to be more specific (English, 2017; Perignat & Katz-Buonincontro, 2019). On the other hand, the perspective based on the critical and contextualizing formation of the STSE approach considers concepts after the context, with problematization being the starting point of the pedagogical process (Pedretti & Nazir, 2011; Santos & Auler, 2019; Santos, 2007).

Although the experimental system was preassembled, the activity required PST to engage in a process of reverse engineering, particularly when working with the mystery box. This involved analyzing sensor data, applying electrochemical principles (e.g., the Nernst equation), and reconstructing the configuration of the hidden concentration cell. By interpreting how the system functioned and proposing how it was built, PST practiced core elements of engineering reasoning, identifying system components, analyzing functionality, and solving technical challenges. This form of reverse engineering served as a meaningful way to integrate the engineering dimension into the STEM-lab activity.

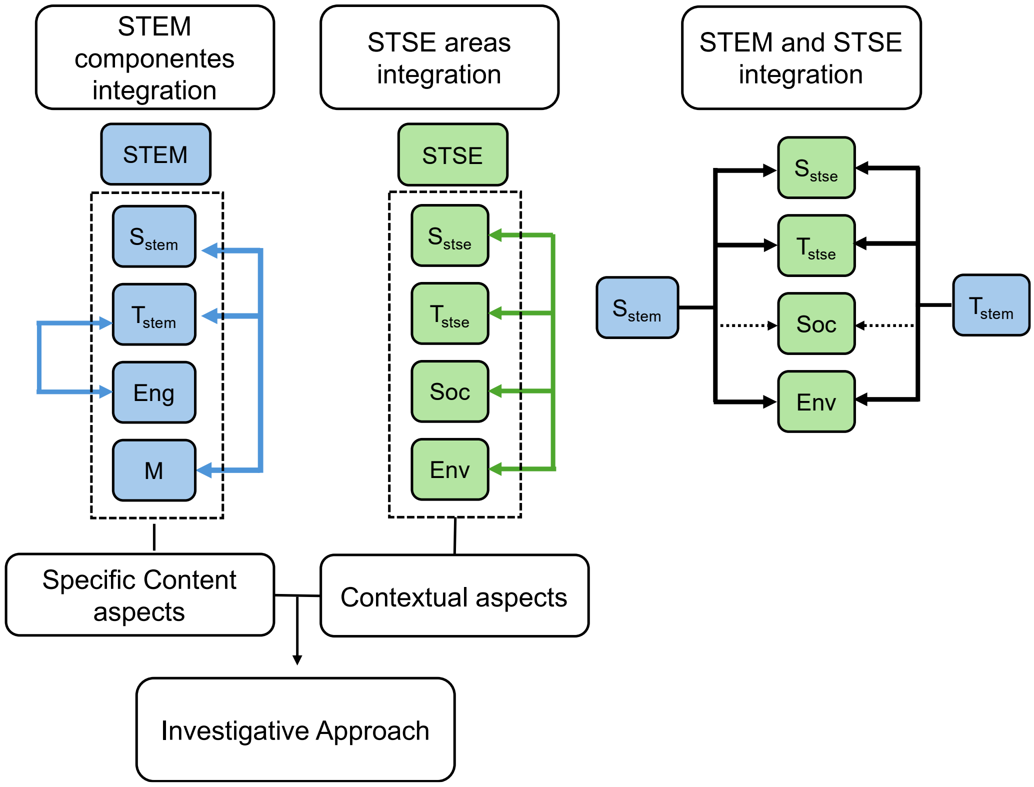
Although the Arduino code was provided in advance, PST could engage in exploring and discussing its logic, suggesting small adjustments and considering how to adapt it to different school contexts. This process offers elements of computational thinking, such as debugging, conditional reasoning, and problem-solving strategies.

Despite this apparent disparity, not only are there connections between the STEM disciplines and STSE areas, but a complementary nature is also expected. It is noted that science and technology are integrated into concepts. However, in STEM education, more content-specific concepts are presented, and in STSE, more general aspects are presented. This fact seems interesting because it allows us to consider that the contextual approach brings complementarity to STEM education, enabling the creation of meanings for the specific chemistry contents.

The explicit absence of articulations between the areas of engineering and mathematics with the STSE areas may be related to the epistemological specificity of the former and also because, in the case of engineering, this is a field that is unfamiliar to teachers in training and, in the case of mathematics, its recognition in a procedural sense, that is, as a set of tools that are used by other sciences. Recognizing these aspects as deficient is important, and it is possible to think about integrating training strategies that can help overcome such difficulties.

It is also noted that in developing laboratory activity integrated with technologies and considering STEM education and the STSE approach, the pedagogical approach, in this case, teaching through investigation, brings potential elements for working with STEM skills and with content specific. To systematize these findings, Figure 6 provides a diagram highlighting the connections identified throughout the data analysis. To differentiate Science and Technology in STEM and STSE, we used S_{steam}, T_{steam}, S_{stse} and T_{stse}.

Figure 6. *Schematic diagram of the integration between STEM disciplines and STSE areas*



CONCLUSIONS

In this study, we integrated technological tools into an experimental electrochemistry activity aimed at enhancing the training of future chemistry teachers from a STEM education and STSE approach. This allowed us to evaluate how PST engage with and reflect on the STEM content during the activity, understanding their ability to contextualize the content for high school settings, and assessing the practical challenges and opportunities they identify.

Revisiting our research objectives, our findings reveal that PST could identify various STEM contents, although they faced difficulties, particularly with the engineering aspects. The elements associated with STEM disciplines were recognized in a specific manner to each content area, while those linked to the STSE approach appeared more contextual, as aspects related to environmental issues but not related to a specific chemistry content, suggesting that a synthesis of these educational fields may promote an approach that starts from a broader context to work with specific content. These data are directly related to objectives 1 and 2. It is important to emphasize that this activity involves a system that was not developed by the PST, and, therefore, some limitations to the recognition of content related to electronics and engineering were not possible to be developed.

However, we emphasize that the proposal sought to integrate STEM education into a didactic proposal, the STSE approach with an activity that inserts the contents of chemistry into a more global context and also integrating an investigative strategy. This association has been recommended in the literature as a perspective for learning in STEM areas and, in our work, it was possible to outline results that allow us to think about teacher training, improving the practice carried out.

Considering objective 3, notably, the PST proposed only a few new contexts for applying the activity, which may reflect their limited involvement in its initial development. This underscores the potential benefits of engaging teachers more deeply in the creation of educational materials, a practice that could be explored in future research. The PST also demonstrated a reflective engagement with the activity, noting both its strengths in fostering pedagogical knowledge and areas needing adjustment to better suit high school environments.

Thinking about the possibilities of adapting the proposal to classroom contexts allows PST to understand what demands would be necessary in terms of materials and the necessary knowledge. This aspect is fundamental in the development of future didactic proposals involving any didactic proposals. In this sense, by reflecting and identifying paths and challenges, these professionals can be developing professional knowledge for working with STEM education.

It is important to note, however, that some limitations should be pointed out, considering new implementations and reformulations. Although we have here a proposal that seeks to integrate technologies and contemplate a formative perspective, we emphasize that the number of subjects investigated is low, which leads us to an analysis with a greater qualitative focus. There is also the fact that the participants were between 21 and 55 years old, and therefore had different levels of interaction with technology. These reflections, in our view, do not remove the substitution of the study that also involved the development of an experimental system and a set of instruments that can be implemented in different situations, including an analysis with more subjects and with a focus on the validation of quantitative instruments.

Conclusively, this study not only highlighted some strengths and limitations of the current approach but also encouraged a critical reflection on the adaptations needed to make STEM activities more applicable and effective in educational settings. These insights contribute to the field of Chemistry Education illustrating how teacher training proposals can advance in STEM education and encourage reflection on future research in this area.

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