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HISTORY OF RADIOACTIVITY IN THE CLASSROOM: EVALUATING THE IMPACT OF DIDATIC SEQUENCE BASED ON THE "RADIUM GIRLS" EPISODE

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Abstract
The introduction of the History and Philosophy of Science in the educational context can enable critical reflections on science as a social and cultural practice. In this work, we present the results of an empirical investigation carried out through the implementation of a didactic sequence focused on discussions about the Nature of Science, gender, and social justice, contextualized by the historical episode of the Radium Girls. The proposal was implemented in a 9th-grade class of Basic Education, based on activities structured according to the three pedagogical moments, with the central point being the use of historical-pedagogical narratives. We applied content analysis methodology to the written productions prepared by the participants in the final stage of the intervention. The results indicate critical understandings of science as a historical construction influenced by economic and social interests, as well as reflections on gender inequalities, scientific responsibilities, and labor rights. The evidence suggests that the approach fostered awareness of the social and ethical implications of science, contributing to a more critical and humanized perspective of scientific knowledge.
Keywords: Radium Girls. Nature of Science. History of Radioactivity.

História da Radioatividade em Sala de Aula: avaliando impactos de uma sequência didática baseada no episódio das Garotas do Rádio

Resumo
A introdução da História e Filosofia da Ciência no contexto didático possibilita reflexões críticas acerca da ciência enquanto prática social e cultural. Neste trabalho, apresentamos os resultados de uma investigação empírica realizada ao longo da implementação de uma sequência didática centrada em discussões sobre a Natureza da Ciência, gênero e justiça social, contextualizadas a partir do episódio histórico das Garotas do Rádio. A proposta foi aplicada no 9º ano do Ensino Fundamental, tomando como base atividades estruturadas segundo os três momentos pedagógicos, tendo como ponto central a utilização de narrativas histórico-pedagógicas. Aplicamos a metodologia da análise de conteúdo às produções escritas elaboradas pelos participantes na etapa final da intervenção. Os resultados indicam compreensões críticas sobre a ciência como construção histórica, influenciada por interesses econômicos e sociais, assim como reflexões sobre desigualdades de gênero, responsabilidades científicas e direitos laborais. As evidências sugerem que a abordagem favoreceu a consciência sobre as implicações sociais e éticas da ciência, contribuindo para uma perspectiva mais crítica e humanizada do saber científico.
Palavras-Chave: Garotas do Rádio. Natureza da Ciência. História da Radioatividade.

Historia de la Radiactividad en el aula: evaluando los Impactos de una secuencia didáctica basada en el episodio de las Chicas del Radio

Resumen
La introducción de la Historia y Filosofía de la Ciencia en el contexto didáctico puede posibilitar reflexiones críticas acerca de la ciencia como práctica social y cultural. En este trabajo, presentamos los resultados de una investigación empírica realizada a lo largo de la aplicación de una secuencia didáctica centrada en discusiones sobre la Naturaleza de la Ciencia, género y justicia social, contextualizadas a partir del episodio histórico de las Chicas de la Radio. La propuesta fue aplicada en el 9º grado de la Educación Básica, tomando como base actividades estructuradas según los tres momentos pedagógicos, teniendo como eje central el uso de narrativas histórico-pedagógicas. Aplicamos la metodología del análisis de contenido a las producciones escritas elaboradas por los participantes en la etapa final de la intervención. Los resultados indican comprensiones críticas sobre la ciencia como construcción histórica, influenciada por intereses económicos y sociales, así como reflexiones sobre desigualdades de género, responsabilidades científicas y derechos laborales. Las evidencias sugieren que el enfoque favoreció la conciencia acerca de las implicaciones sociales y éticas de la ciencia, contribuyendo a una perspectiva más crítica y humanizada del saber científico.
Palabras clave: Chicas del Radio. Naturaleza de la Ciencia. Historia de la Radiactividad.

1. INTRODUCTION

Over the past decades, the integration of the History and Philosophy of Science (HPS) into science education has attracted increasing attention from researchers. This approach stands out for fostering a deeper understanding of science knowledge by presenting it as a human, social, cultural and historical construct. Historical contextualization, grounded in the presentation of science as a process rather than a finished product, can contribute to students' learning of scientific concepts and to the development of their critical thinking (Matthews, 1995; Allchin, 2004; Martins, 2006; Prestes & Caldeira, 2009; Forato et al., 2011; Vital & Guerra, 2017; Rodrigues et al., 2020).

Research has shown that the discussion of historical episodes can enhance science learning by encouraging reflection on the Nature of Science (NOS), for example, regarding the relationship between among science, technology, and society, as well as the social and ethical implications of science practices. Examples can be found in: Silva e Moura (2008), Forato et al. (2012), Schirmer e Sauerwein (2014) e, Rodrigues et al. (2020).In this context, HPS has emerged as a promising strategy for challenging simplistic and stereotypical views of science by portraying it as a human, collaborative and historically situated endeavor, as discussed by Martins (2007), Prestes e Caldeira (2009), Martins (2015) e, Oliveira et al. (2021).

In the Brazilian context, from the National Curriculum Parameters to the National Common Curricular Base, educational legislation highlights the importance of historically contextualized and interdisciplinary approaches (Brazil, 1997, 2001, & 2018). These documents point to the need to foster learning situations that are challenging, ethical, and socially situated, leading to an understanding of science as a collective, evolving human social endeavor.

It should be noted, however, that despite academic and legal recommendations, the presence of the history and philosophy of science (HPS) in classrooms remains limited. This limitation is linked, among other factors, to a lack of specific teacher training for using historical-philosophical approaches, gaps regarding HPS content in textbooks, and curricular overload. Instruction tends to focus on preparing for exams that do not explicitly cover this type of content. Furthermore, teachers rarely view HPS as a strategy that facilitates the teaching of material found in entrance exams (Martins, 2006; Martins, 2007; Forato et al., 2012; Schirmer & Sauerwein, 2014; Vital & Guerra, 2017; Hidalgo, 2023).

Among the most frequently proposed resources to expand the presence of HPS in education are historical-pedagogical narratives, texts based on historical episodes adapted for the school context. These narratives combine factual elements, grounded in historiographical research, with storytelling techniques that stimulate students' interest and imagination. They allow scientific content to be addressed in a more engaging way, fostering connections between concepts and historical contexts (Drummond et al., 2015; Vital & Guerra, 2016; Oliveira et al., 2021). It must be emphasized, however, that a review of Brazilian journal publications regarding the didactic integration of HPS, specifically "state-of-the-art" studies, indicates that "the majority of works do not present an evaluation of the use of these resources in the implemented proposals" (Schirmer & Sauerwein, 2014, p. 61).

Given this scenario, we evaluated the implementation of a self-developed didactic sequence with a historical-philosophical focus in the 9th grade of elementary/middle school. The proposal, centered on the historical episode of the "Radium Girls," addresses the history of radioactivity. It employs narratives designed

to prompt reflection on the Nature of Science (NOS), gender relations, labor rights, and social responsibility. The approach is based on the premise that discussing real-world cases fraught with dilemmas and conflicts creates an opportunity to develop not only students' conceptual knowledge but also their critical thinking and argumentative skills.

This article presents the results of qualitative empirical research conducted during the intervention. We sought to investigate whether, and to what extent, the proposed teaching sequence could stimulate critical reflection on the episode in question, thereby contributing to a historically and socially contextualized view of science. Below, we briefly describe the selected historical episode and the structure of the teaching sequence, setting the stage for a discussion of the research findings[1].

2. THE RADIO GIRLS EPISODE

In the early 20th century, the discovery of radioactivity sparked great enthusiasm. Various products containing radium[2], such as chocolates, tonics, toothpaste, cosmetics, and medicines, began to be marketed. This excitement also drove the manufacture of watches with luminous dials painted with radioactive paint, particularly starting around World War I (Leal & Forato, 2021).

The United States Radium Corporation (USRC) hired hundreds of young women to paint these watch dials. These workers, known as the "Radium Girls," were instructed to shape the tips of their brushes with their mouths to ensure painting precision. The company assured them that this procedure, known as "lip-pointing", was safe, even though there was already evidence suggesting radium could be harmful to health (Leal, 2023)[3].

Over time, many of these young workers fell seriously ill, developing jaw necrosis, cancer, and other debilitating conditions. In 1927, five workers sued the USRC, facing a legal battle marked by procedural obstacles, gender bias, and the industry's powerful status. Despite the evidence, the USRC denied any link between the workers' jobs and their severe health problems, going so far as to conceal reports produced by researchers hired by the company itself, reports that documented the need to change working conditions. Professionals hired by the USRC were responsible for examining the women; in one instance, they even misdiagnosed a worker with syphilis instead of radioactive paint poisoning. The employees' personal lives were investigated and publicly exposed, leading to social stigma for some, most notably in the case of a single mother. Independent doctors faced resistance when attempting to investigate the situation, and the USRC obstructed access to the radioactive paint. It was only in the context of the trial, drawing on the studies by pathologist Harrison Martland (1883–1954) regarding the toxicity of radium in living organisms, that it became possible to demonstrate that small amounts of radium accumulating in the bones were lethal. With the support of the National Consumers League, the young female painters secured a legal settlement in 1928 (Leal, 2023). That same year, Marie Curie (1867–1934), in a newspaper interview about the case, expressed concern regarding the indiscriminate use of radium in the United States, acknowledging that once absorbed by the body, the radioactive material could not be removed (The Daily Notes, 1928).

The "Radium Girls" case had widespread repercussions, driving changes in labor legislation and occupational safety standards in the United States (Leal & Forato, 2021). From an educational standpoint, this episode is particularly powerful as a context for discussions on the Nature of Science (NoS), the relationship between science and society, labor rights, gender issues, and ethical dilemmas. It highlights multiple dimensions of scientific practice: the provisional nature of knowledge, conflicts between economic interests and ethical values, the influence of culture on science, and the social impacts of scientific activity.

3. DESCRIPTION OF THE INTERVENTION

The implemented instructional sequence [4] sought to integrate conceptual, historical, ethical, and social aspects related to the "Radium Girls" episode, aiming to foster critical and explicit reflection on assertions and issues

[1] This work is an excerpt from the master's thesis developed by the first author, under the guidance of the second. The thesis is available in the electronic repository of UFRN (Medeiros, 2025).

[2] Radium is an alkaline earth metal discovered by Marie and Pierre Curie in 1898 from uraninite. It is highly radioactive, emitting alpha, beta, and gamma radiation. Its best-known isotope, radium-226, has a half-life of approximately 1600 years. Its salts exhibit luminescence, a phenomenon that led to its application in watch dials, aviation instruments, and military equipment, although today its use is limited to medical applications (Xavier et al., 2007).

[3] Pierre Curie's (1859-1906) speech at the Nobel Prize ceremony in 1905 indicated that, in certain cases, the action of radium could be dangerous, causing burns that were difficult to heal upon contact with the skin (Cordeiro & Peduzzi, 2010).

[4] We refer to a didactic sequence as a set of interconnected teaching-learning activities on a topic to be taught (Méheut & Psillos, 2004;

concerning the Nature of Science (Martins, 2015; Peduzzi & Raicik, 2020). In this regard, key objectives included: understanding science as a historical, social, and cultural construct; recognizing the provisional nature of scientific knowledge; analyzing the impact of science on society and the resulting ethical dilemmas; and discussing issues related to gender inequality. Furthermore, the initiative aimed to foster the development of students' written and oral argumentation skills.

The proposal, structured based on the "three pedagogical moments" (Delizoicov et al., 2002), was implemented in a 9th-grade Science class, a choice justified by the inclusion of the topic of radioactivity in textbooks for this grade level. It involved the reading and collective discussion of four original historical-pedagogical narratives (Figures 1–4), accompanied by reading-guidance questions embedded within the texts[5].

Context of Radioactivity

Between the late 19th and early 20th centuries, the discovery of X-rays and radioactivity marked a major breakthrough in science. These discoveries stimulated extensive research to understand new phenomena and explore their potential applications. While X-rays made it possible to "see," for example, aspects of the inside of the human body through radiographs, radioactivity also sparked interest, both for medical applications and for the pharmaceutical, food, cosmetics, and other industries.





Figure 1: Marie Curie & Pierre Curie

The scientist couple, Marie Curie (1867-1934) and Pierre Curie (1859-1906), dedicated themselves to the study of radioactivity, playing a fundamental role in isolating the element radium. They discovered that radium was more active in uranium minerals than other elements they used in their research.

Marie and Pierre Curie's research was recognized with Nobel Prizes in 1903 and 1911, demonstrating the impact of the discovery of radioactivity at the time.

Shortly after the discovery of radium, society in general and the industry became interested in the new element. Radium mines emerged in the United States and various products with added radium appeared, which generated enthusiasm and attraction among people.

Clocks were manufactured with dials painted with radium-based paint, which glowed in the dark thanks to radioactivity. The list of radioactive products marketed in the early 20th century included suppositories, toothpaste, radioactive compresses, radioactive water, cigarettes, chocolates, condoms, brilliantine, atomic soda, and soaps, in addition to makeup items. Below, we see some images of these products that contained radium.

Figure 1: Text 1, radioactivity context. Source: the authors.

The narratives explore various dimensions of the historical episode of the Radium Girls, serving as a basis for introducing issues related to the Nature of Science (NOS), ethics, and gender relations.

Psillos et al., 2004).

[5] The narratives are available in Medeiros (2025).

The first text, titled “Context of Radioactivity,” highlights the discovery of radioactivity in the late 19th century and its almost immediate application in the manufacture of commercial products, such as cosmetics, foods, medicines, and watches with luminous hands. It describes the public fascination with the glow of radium and how this novelty became associated with modernity and progress, initially without any consideration of potential risks.

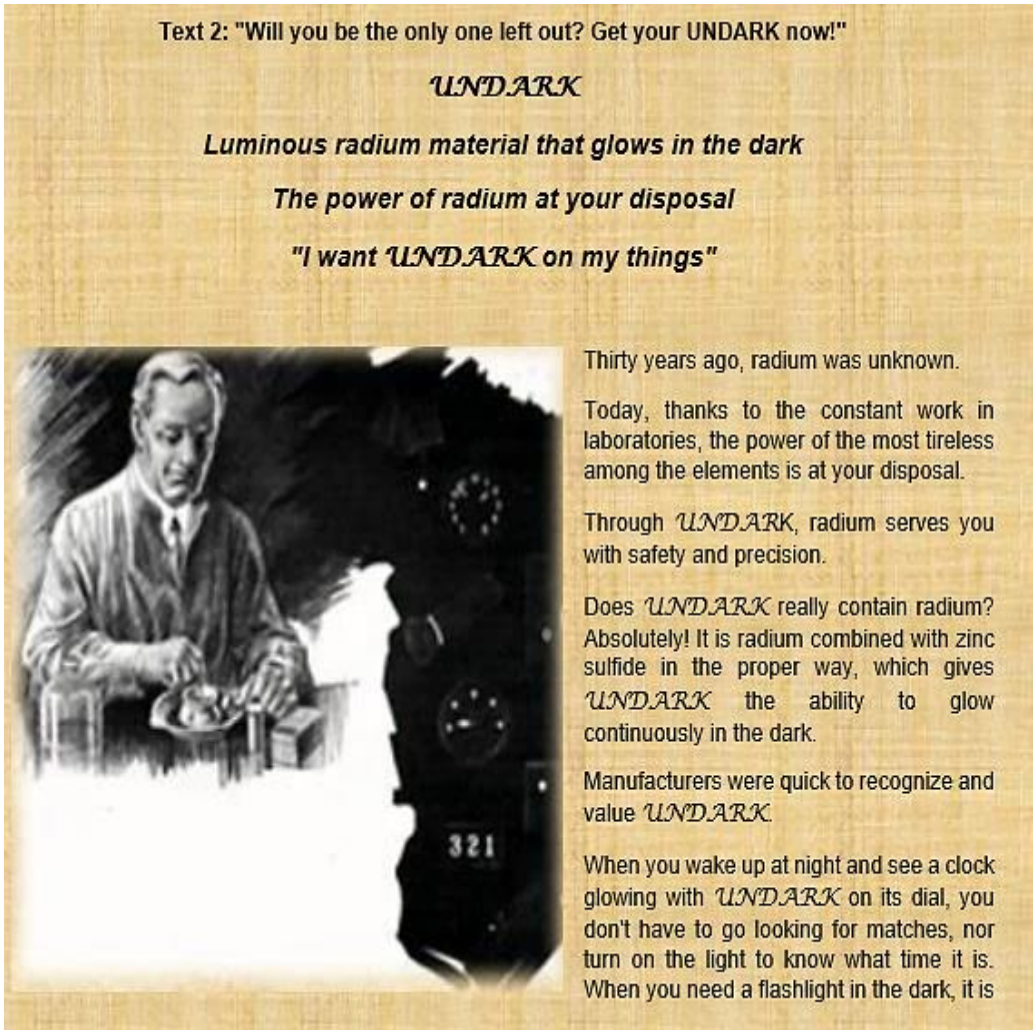


Figure 2: Text 2, advertisement. Source: the authors.

The second text, entitled “Are you going to be the only one left out? Get your UNDARK now,” presents, in an advertising format, the enthusiasm surrounding the radium-based luminous paint used to paint watch dials.

The appealing and persuasive tone highlights the companies' marketing strategy, which promoted the product as modern and necessary, without mentioning any health risks in its handling. This narrative was entirely developed from excerpts of real advertising campaigns from that time.

The third text, “Radium Girls,” recounts the daily work routine of the young female laborers hired by the USRC, focusing on watch-painting techniques, hazardous working conditions, and the lack of radiation protection. It describes how women were hired on a large scale at low wages to perform the “lip, dip, paint” technique, being instructed to use their lips to shape the brush tips to a fine point, a practice that led to the ingestion of radioactive paint.

The narrative depicts the worsening health of the female workers, the symptoms of radium poisoning, and the negligence of the company and medical authorities, the latter often hired by the company itself. The

text also addresses strategies to conceal information regarding the contamination, including findings from researchers, as well as false diagnoses and attempts to discredit the workers' allegations.

Text 3: Radium Girls

The historical episode of the "Radium Girls" took place alongside the advances in the discovery of radioactivity. As we saw in the previous texts, the fascination with radioactivity led to the production of various items, including clocks that glowed in the dark, whose advertisements were highly appealing.

These clocks were initially manufactured in Europe, primarily in Germany and Switzerland. Then, between 1913 and 1914, they also began to be manufactured in the United States, following the creation of the Radium Luminous Material Corporation, later known as the United States Radium Corporation (USRC).



Figure 1: Facade of the USRC Factory



Figure 2: Interior of the USRC Factory

In the United States, the success was so immense that production jumped from 8,500 clocks to 2,200,000 in just four years. In 1918, 95% of all radium extracted in the country was used to make paint for clock dials. In 1919, 560,000 clocks were exported, and by 1925, production reached 5,500 clocks per day.

Because men had been sent to World War I, companies hired young women to paint the clock hands, taking advantage of the exploitation of this cheap labor. The young women saw the work as a way to contribute to household expenses. Furthermore, the job allowed them to feel like part of society, since, at that time, they had few rights. Women could not vote and did not have access to Higher Education.

Figure 3: Text 3, historical episode. Source: the authors.

The fourth and final text, titled “The Quest for Justice,” focuses on the mobilization of female workers in a lawsuit against USRC and the consequences of the “Radium Girls” episode, including the recognition of the dangers arising from unsafe exposure to radioactive materials.

The narrative outlines the struggle to gain recognition for occupational illnesses, the case's impact on labor legislation, and the eventual ban on the use of radium in consumer products.

Text 4: The Search for Justice



In May 1927, five young clock dial painters, dissatisfied with their diagnoses and the deterioration of their health, decided to file a lawsuit against the USRC. They were: Quinta McDonald, Edna Hussmann, Albina Larice, Katherine Schaub, and Grace Fryer.

The young women faced a long battle, as it was even difficult to find lawyers willing to represent them against a large company the size of the USRC. The "five doomed women," so called because doctors predicted they would die, obtained the support of a relatively inexperienced, newly graduated lawyer. At the time, discussions about labor issues in the United States were just beginning. The National Consumers League, an entity then committed to these issues, also supported the cause of the young workers.



Figure 1: The "five doomed women"

In a society that until then had been used to viewing radium as beneficial and used it in various popular and profitable products—including medicines, cosmetics, and food items—how could one argue that this substance was making the workers sick? If radium was prescribed for the treatment of cancer and tuberculosis, how could it be so harmful?

Figure 4: Text 4, the quest for justice. Source: author's own.

Titled "Focus on the Text," the reading-guidance questions provided with each narrative serve as a springboard for group discussions in the classroom, enabling the exploration of aspects outlined in the intervention's objectives.

This stage, the core of the proposal, is preceded using audiovisual resources, such as the report "Cesium-137: 30 Years"[6] (aired by Rede Globo's Fantástico program). This aims to raise student awareness regarding the dangers of improper contact with radioactive materials and to highlight that such incidents have indeed occurred in Brazil.

During this initial phase of problematization, questions are raised about when the harmful effects of radioactive substances were first historically observed; this paves the way for the knowledge-organization stage, in which the popular science video "Radium Girls"[7] is used to introduce the historical episode explored in the narratives (see **Table 1**).

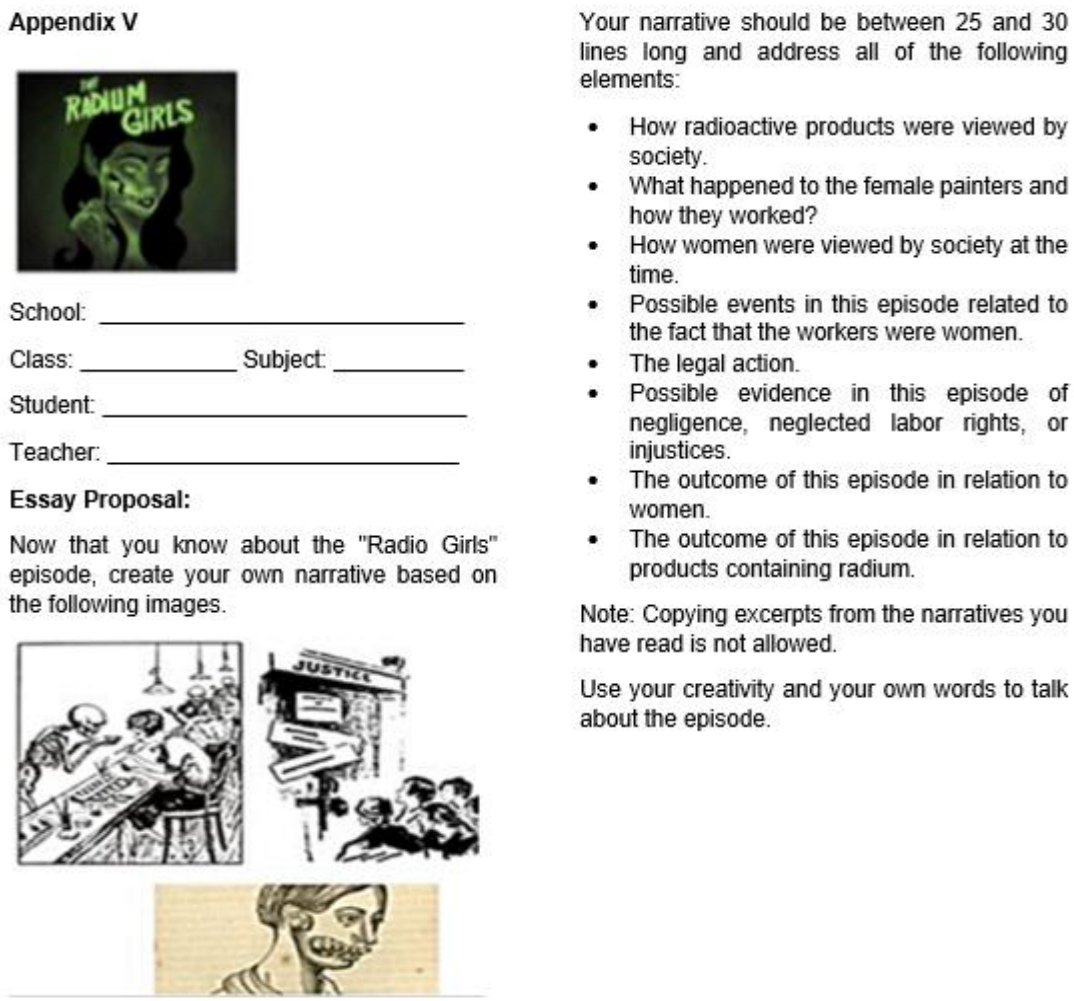
[6] Available at: https://www.youtube.com/watch?v=VUHLS1WL6FM&t=382s

[7] Available at: https://www.youtube.com/watch?v=wkfNkd21KQc

Table 1: Stages of the didactic sequence. Source: author's own.

Momentos	Knowledge Problematization	Knowledge organization	Knowledge application
Goals	Elicit the participants' prior knowledge regarding radioactive materials and the potential risks of undue exposure to radioactivity. Stimulate the students' curiosity about when these risks were first recognized.	Present the story of the Radium Girls through video and written narratives. Foster an understanding of scientific, historical, ethical, and gender-related aspects, as well as those related to the Nature of Science (NoS).	Interpret images by correlating them with the episode. Write a reflection on the themes addressed in the previous stages.
Activity	Conversational introduction to the topic. Presentation of the report "Cesium-137: 30 Years." Discussion based on the video.	Video screening: “Radium Girls” – The Case of the Radioactive Girls. Group reading session covering the narratives, followed by discussions prompted by reading-guide questions.	Preparation of an individual written piece about the episode, based on images, cartoons, and guidelines for revisiting aspects related to the episode.

Preparation of an individual written piece about the episode, based on images, cartoons, and guidelines for revisiting aspects related to the episode. To conclude the intervention, during the knowledge application phase, students engaged in an individual writing activity. They were provided with a worksheet containing images and cartoons related to the episode, along with instructions to write a text of 25 to 30 lines, recording their own ideas and impressions based on the discussions (Figure 5).



Appendix V

School: _____

Class: _____ Subject: _____

Student: _____

Teacher: _____

Essay Proposal:

Now that you know about the "Radio Girls" episode, create your own narrative based on the following images.

Your narrative should be between 25 and 30 lines long and address all of the following elements:

- How radioactive products were viewed by society.
- What happened to the female painters and how they worked?
- How women were viewed by society at the time.
- Possible events in this episode related to the fact that the workers were women.
- The legal action.
- Possible evidence in this episode of negligence, neglected labor rights, or injustices.
- The outcome of this episode in relation to women.
- The outcome of this episode in relation to products containing radium.

Note: Copying excerpts from the narratives you have read is not allowed.

Use your creativity and your own words to talk about the episode.

Figure 5: Image of the instruction sheet for the individual written activity. Source: author's own.

They must also examine the visual representations, considering the following aspects: society's perception of radioactive products; the fate of the young female painters and their working conditions; societal views on women at the time; events directly linked to the fact that the workers were women; evidence of negligence, labor rights violations, or injustices; and the eventual outcome for the girls and the radium-containing products. These aspects align with the central objectives of the instructional sequence, making the activity essential for assessing student understanding.

The proposal was initially implemented as a pilot study, to validate the educational product, at Manoel Patrício de Figueirêdo State School, and subsequently for data collection at Padre Edmund Kagerer State School; both schools are located in the city of Caicó, Rio Grande do Norte, and the activity was conducted with 9th-grade classes in 2024[8]. It took place during regular class hours rather than as an extracurricular activity. The implementation spanned a total of eight 50-minute lessons. The researcher, the lead author of this article, was the school's science teacher at the time and directly conducted all stages of the intervention. The research methodology and results are presented below.

4. METHODOLOGY

The research conducted was empirical and qualitative in nature. We sought to identify potential impacts of implementing the instructional sequence, considering the proposed objectives regarding the understanding of the historical episode and discussions related to the Nature of Science (NoS). For the purposes of the research, the participants' written work was analyzed.

We began by reading each participant's written work. This initial review revealed that an individual analysis of the written work could be conducted based on *a priori* criteria derived from the instructions given to the participants on the worksheet provided for the activity (**Figure 5**). Thus, the criteria used, regarding the content covered, align with the instructional sequence objectives previously outlined in this article. Below, we list each criterion accompanied by a brief description of the aspects the participants were expected to address:

- Societal perception of radioactive products – understanding the context of social acceptance regarding the use of radium, its commercial success, and the lack of awareness concerning potential risks.
- Working conditions and the fate of the women – aspects related to watch-dial painting procedures, working conditions, and the illness and death of the female painters.
- Societal views on women – gender issues highlighted by the episode, such as the exploitation of female labor, the discrediting of the painters, and the difficulties in securing legal support.
- Negligence, violations, or injustices – the company's failure to disclose risks, the concealment of scientific reports, fraudulent medical evaluations, and conflicts of interest surrounding the case.
- The story's outcome – the episode's repercussions in social, labor, and scientific spheres, among others.

Thus, the participants' written work was analyzed individually (Section 5.1) to identify elements that demonstrated reflections, contextualized by the episode, on aspects of the Nature of Science (NoS), scientific practices, and the relationship between science and society. Furthermore, the originality and length of the text produced were considered as analysis criteria, observing whether the participant presented their own ideas, established connections with other contexts, and developed the topic with an appropriate level of depth. We also checked whether the text met the length recommended in the guidelines[9].

In addition to the individual analysis of each participant's written work, we conducted a second type of analysis, a general one based on thematic axes (i.e., categories that emerged from reading the written texts), applying the content analysis methodology (Bardin, 2004).

These axes not only organize the data analytically but also reveal the multiple dimensions through which participants interpreted the historical, ethical, scientific, and social aspects of the case. The five central

[8] The execution of this research was authorized by the responsible parties according to the Free and Informed Consent Form (see Medeiros, 2025).

[9] The choice to produce written assignments is part of a coordinated school initiative aimed at improving students' writing skills, as part of a gradual process that begins in the 7th grade and extends to the 9th grade. This practice aims to prepare students for future educational opportunities, especially considering the encouragement of participation in selection processes for admission to the Federal Institute of Education, Science and Technology of Rio Grande do Norte. Thus, the text production carried out in the third stage of the intervention also aligns with institutional strategies for valuing writing as a tool for educational and social development. For this reason, the analysis of the written productions will also include comments regarding any argumentative and linguistic difficulties the students may have. We also consider that any difficulties in this regard impact how students articulate, in writing, the content covered in the episode.

thematic axes identified—which reflect how participants made sense of the “Radium Girls” episode and drew upon the material covered—are:

- Axis 1 – Scientific knowledge develops within contexts shaped by economic and social interests;
- Axis 2 – Invisibility and gender inequality;
- Axis 3 – Ethical dimension and scientific responsibility;
- Axis 4 – Provisional nature and transformation of scientific knowledge;
- Axis 5 – Social justice and critical stance.

These five interpretive axes, not mutually exclusive, intertwine and engage with the objectives of the didactic sequence. In this second analysis (Section 5.2), findings from the written work were cross-referenced with any oral contributions made by the students during the implementation of the didactic sequence[10].

5. RESULTS AND DISCUSSION

Fourteen students participated in the intervention and completed the final written activity; they are identified in the subsequent discussions as Pn, where n ranges from 1 to 14. Of this total, five were girls (P_1, P_5, P_7, P_{11}, and P_{12}) and nine were boys (P_2, P_3, P_4, P_6, P_8, P_9, P_{10}, P_{13}, and P_{14}), aged between fourteen and fifteen[11].

5.1. Individual analysis of written production

P1 acknowledged society's positive perception of radioactive products linked to medical uses. The participants showed a partial understanding of the painters' working conditions, mentioning illnesses but without detailing the work procedures. Regarding the social view of women, the participant did not explicitly state it but suggested it was negative due to the difficulty in accessing justice. The participant identified corporate negligence but did not delve into the role of doctors hired by USRC or the justice system: "The company didn't care about what was happening to the girls. It just wanted to keep selling its radium products." The outcome of the episode was addressed only partially, limited to the 1925 warning about risks. The text revealed original authorship and a spontaneous style, albeit with errors regarding standard language conventions. It did not meet the expected length, resulting in a short piece. Overall, the participant demonstrated an initial understanding of the episode, a developing critical perspective, and engagement with the subject matter.

P2 acknowledged society's positive perception of radium, associating it with benefits while lacking awareness of the risks. The participant clearly described the working conditions, including the painters' direct contact with radioactive paint and its negative health effects. They offered a critical perspective on how society viewed women, highlighting political, educational, and workplace inequalities. They highlighted the company's negligence in continuing production even after complaints and symptoms of illness among the employees: "They knew radium was harmful but didn't warn anyone. That was a choice." The outcome of the episode was addressed partially, without details on the legal process or reparations for the workers. The writing showed original authorship, spontaneity, and a distinctive style, despite errors regarding standard language conventions. The text met the required length and presented a consistent argument. Overall, the participant demonstrated a good understanding of the episode, showing critical insight and a solid grasp of the themes addressed.

P3 highlighted society's positive perception of radium products, which were viewed as safe and innovative. The participant described the precarious working conditions faced by the female painters, including direct exposure to radiation and a lack of hygiene and proper nutrition. They highlighted the negative social perception of these women, who were subjected to terrible working conditions while replacing men who were away at war, and pointed out the watch company's negligence in mandating harmful practices, such as shaping paintbrush tips with their mouths: "If they had been warned beforehand, perhaps many of the girls would still be alive." The outcome of the episode was addressed only partially; while the fatalities were acknowledged, the lawsuit was not mentioned. The writing displayed simplicity and grammatical errors but demonstrated authenticity in its development. The text length was appropriate and met expectations. The participant's work indicated a critical understanding of labor exploitation, the risks of radioactivity, and gender inequality.

[10] Audio recordings were made of the discussions and interactions throughout the application of the teaching sequence. Transcripts of the participants' speech are available in Medeiros, 2025.

[11] We differentiate between boys and girls here, as we considered it relevant to observe whether there was a difference between these groups regarding awareness and empathy towards gender issues related to the episode.

P4 noted the commercial success of radioactive products but did not detail the benefits perceived by society. The participant mentioned the deaths and low wages of the female workers without delving into the specific working conditions. They highlighted the exploitation of women in the workplace but did not discuss other social aspects of the era. Regarding the status of women, they contrasted the withdrawal of products from the market following the death of athlete Eben Byers with the lack of precautionary measures taken after the deaths of the female painters, even though both cases involved radium contamination: "When the rich man died, they took notice. But the girls were poor and female; no one paid attention." Thus, they pointed to signs of corporate negligence, although they did not fully explore the events that transpired. The episode's conclusion was addressed partially, mentioning the deaths and the halt in production but omitting details regarding reparations. The work was deemed only partially original due to indications of reliance on external sources. The length was appropriate and met requirements. Overall, P4's text demonstrated a basic understanding of the episode but lacked critical depth and historical contextualization.

P5 acknowledged the dangers of radioactivity but did not highlight the commercial success and benefits touted in advertisements. The participant noted how knowledge regarding the risks of radioactivity evolved over time: "Science thought about one thing at first, but that changed later as more studies were conducted." They clearly described the working conditions, the women's symptoms, and the false medical diagnoses. They pointed out gender biases, such as accusations of syphilis and the dismissal of the women's complaints. They highlighted the company's negligence and bad faith, noting its sole focus on reputation and financial gain. The outcome of the episode was addressed in a limited manner, mentioning the forced settlement and the deaths without delving into the legal challenges. The writing was personal, spontaneous, and authentic, despite grammatical errors. The text met the length requirement but could have included more detail. P5's text demonstrated a critical perspective and sensitivity to the workers' suffering, though it lacked deeper historical and social analysis.

P6 referred to the popularity and commercial success of radioactive products, highlighting the role of advertising. The participant mentioned working conditions and illnesses but presented a contradiction regarding the practice of pointing the brush with one's mouth, describing it at times as a company requirement and at others as the painters' own choice. They pointed to the exploitation of women in the labor market, citing lower wages and the need to prove their competence, but did not explore other social aspects in depth. They noted the company's denial of health issues, although they also partially attributed responsibility to the workers themselves. The outcome of the episode was addressed briefly, referring to only the deaths without mentioning lawsuits or compensation. They touched upon ethical issues regarding science: "Today we have laws because of these girls. It shows that science needs to consider people." The writing reflected the author's unique voice and spontaneity, despite spelling errors and difficulties in articulating ideas. The text length met the requirements. Overall, the submitted work demonstrated a basic understanding of the episode, though it lacked coherence, critical depth, and socio-historical insight in certain aspects.

P7 highlighted the public enthusiasm for radioactive products, emphasizing the lack of awareness regarding the risks. The participant provided a detailed description of the precarious working conditions, the symptoms, and the deaths of the women. She mentioned the workers' struggle to obtain justice and pointed out the contrast in treatment compared to when a wealthy man fell ill and died. She highlighted corporate negligence, including the use of fake doctors, the manipulation of medical test results, and the refusal to pay compensation. She recounted the legal proceedings, the financial settlement, and the consequences following the death of the young athlete Eben Byers regarding the withdrawal of radioactive products from the market. She linked the episode to contemporary accidents, broadening the analysis to other contexts. The writing showed a distinct voice, clarity, and good structure, reflecting personal engagement with the topic. The length was appropriate, meeting the requirements. The text revealed a critical perspective and sensitivity toward the injustices involved, effectively connecting science, society, and gender.

P8 highlighted society's positive perception of radium, associating it with innovation and commercial success. The participant mentioned the contamination of the female painters resulting from direct contact with radiation but did not detail specific practices or mention the deaths. He did not address societal views regarding women, failing to link the episode to gender inequalities. He pointed out corporate negligence, mentioning the acceptance of a lower compensation amount, but did not address the issue of false diagnoses. The participant described the outcome of the episode only partially, limiting it to the compensation offer without referencing the more severe consequences. The writing was simple and original but contained errors and struggled with flow. The text was brief and did not meet the required length. The work demonstrated a basic understanding of the episode but lacked depth and contained significant critical gaps.

P9 highlighted society's positive view of radioactive products, linked to a lack of awareness regarding the risks. The participant mentioned the workers' symptoms and their pursuit of justice but did not detail the

precarious working conditions. Gender inequality was indirectly highlighted through the mention of women fighting for rights that were not respected. The legal dispute was cited, yet the injustices committed by the company were not explained. However, the participant linked economic power to the control of information, emphasizing the intentional omission of the problems. The outcome of the case was not mentioned, leaving significant gaps. The writing was original, though there was considerable difficulty in articulating ideas. The text submitted was brief and did not meet the required length; the work demonstrated an initial level of understanding.

P10 highlighted society's interest in radioactive products, noting the glow of the watches and the impact of advertising. The participant mentioned the painters' contact radium, including the habit of licking their brushes and the resulting dental problems, without detailing specific deaths. They pointed to gender inequality as a factor that delayed justice and noted the lack of labor rights, though without in-depth historical context. The company's negligence was mentioned only superficially, without detailing specific omissions or liabilities. While the lawsuit was cited, the outcome, settlement, or serious consequences were not presented. The writing was original and spontaneous, despite some difficulty in articulating ideas. The text was concise but fell short of the requested length. The work demonstrated a basic understanding of the episode but lacked critical, social, and ethical depth.

P11 indicated that society believed in the benefits of radium, though this point was made in a fragmented manner without detail. The participant mentioned the painters falling ill but did not describe working conditions or mention any deaths. They pointed out changes in women's participation in the workforce during the war and suggested gender inequality regarding the recognition of radium's risks. They referred to the public's perception of negligence but did not detail the company's actions. The death of an influential man was cited as a turning point for acknowledging the risks, with no mention of the lawsuit or the workers' fate. The text was original, though the organization of ideas was somewhat difficult. The length was adequate and met the requirements. The work demonstrated a partial understanding of the episode but lacked critical depth as well as social, historical, and ethical contextualization.

P12 highlighted society's initial enthusiasm for radioactive products, acknowledging both the benefits and the unknown risks. The participant described in detail the precarious working conditions, the practice of shaping brush tips with their lips, and the illness and death of the painters. It pointed out the exploitation of women in the labor market, viewing them as cheap labor, but did not address other gender-related aspects. It highlighted the company's negligence, including the mandatory nature of the procedure and the harassment of those who spoke out. The episode's outcome was partially addressed; while deaths were mentioned, there was no reference to the lawsuit or settlement. It emphasized the need for legal regulations to prevent similar tragedies. P12's writing was original and contained pertinent information, despite some writing difficulties. The text was of appropriate length, meeting the requirements. Overall, it demonstrated a critical understanding of the episode and articulated ethical, social, and scientific aspects with sensitivity and engagement with the topic.

P13 highlighted society's initial excitement regarding radium, acknowledging its supposed medical benefits. The participant described the precarious working conditions in detail, including the practice of licking the brushes and the symptoms that appeared in the female workers. It pointed out the exploitation of women, noting that they were viewed as inferior and dependent, and relegated to the domestic sphere. It highlighted the company's negligence and legal manipulation, as well as the devaluation of the victims and the use of false diagnoses. It reported that the commercial use of radium stemmed from an initial lack of knowledge regarding the risks, and subsequently pointed out the companies' resistance to changing practices, even in the face of evidence. The episode's outcome was treated critically, showing that the company was not held accountable and the women did not have their rights fully recognized. The participant's writing was clear, critical, well-structured, and original. The text was of appropriate length, meeting the requirements. It demonstrated a consistent critical analysis, articulating science, ethics, and gender inequality in a mature and in-depth manner.

P14 highlighted society's positive perception of radioactive products, which were viewed as miraculous and linked to commercial success. The participant mentioned the illness of the painters due to contact with radioactive paint but did not cite the brush-licking procedure or the deaths. It touched superficially upon the social limitations faced by women. However, it highlighted that prejudice against women contributed to the dismissal of complaints and delays in acting. It pointed out the company's negligence, including the falsification of medical test results and pressure on the female painters to accept unfair legal settlements. It noted that the production of radioactive items continued even after the first signs of health damage appeared. The writing was original and direct, though there was some difficulty in articulating ideas. The text submitted by P14 is concise and did not meet the requested length. It demonstrated an initial understanding of the events and sensitivity to the subject matter but lacked depth.

Table 2 presents a summary of the results from the analysis of the participants' individual written productions. In the table, NA stands for “not met,” PA for “partially met,” and A for “met.”.

The results reveal that participants were reasonably able to engage with various dimensions of the Nature of Science (NoS), such as the relationship between science and socio-economic interests, the provisional nature of scientific knowledge, the ethical implications of scientific practices, and issues regarding gender inequality and labor conditions. Notably, however, not all participants were able to effectively articulate, in a critical and contextualized manner, the historical, ethical, scientific, and social elements involved in the "Radium Girls" episode. Partial results in this regard were evident in the work produced. Indications were observed of an understanding that scientific knowledge is neither neutral nor definitive, but rather subject to revision and external influences. Reflections emerged concerning gender inequality, the conflict between economic interests and ethics, and the importance of accessible, honest scientific communication.

Table 2: Results of the analysis of individual written productions. Source: author's own.

Participant	Societal perception of radioactive products	Working conditions and the fate of women	Society's view of women	Negligence, violations, or injustices	Outcome of the story	Originality	Length
P_1	A	PA	PA	PA	PA	A	NA
P_2	A	A	A	A	PA	A	A
P_3	A	A	PA	A	PA	A	A
P_4	PA	PA	PA	PA	PA	A	A
P_5	PA	A	PA	A	PA	A	A
P_6	A	PA	PA	PA	PA	A	A
P_7	A	A	PA	A	A	A	A
P_8	A	PA	NA	PA	PA	A	NA
P_9	A	PA	PA	PA	NA	A	NA
P_{10}	A	PA	PA	PA	PA	A	NA
P_{11}	PA	PA	PA	PA	PA	A	A
P_{12}	A	A	PA	A	PA	A	A
P_{13}	A	A	A	A	PA	A	A
P_{14}	A	PA	PA	A	PA	A	NA

The texts produced satisfactorily demonstrate the mobilization of values and understandings regarding science as a social practice. These results suggest that the adopted approach contributed to the development of a more critical, reflective, and humanized view of science. No significant difference was observed between the written work of boys and girls, even regarding issues related to gender inequality. Participants of both genders showed a relatively high level of awareness regarding this topic.

5.2. Thematic axes analysis

Axis 1: Scientific knowledge develops in contexts marked by economic and social interests.

This analytical axis encompasses evidence that participants understood science as a human construct that both influences and is influenced by social, historical, and economic contexts. They recognized that the development of scientific knowledge does not occur in isolation but is deeply linked to the circumstances of the era, such as the interest in radioactivity, the profitability of industries producing radioactive goods, flaws in labor legislation, and prevailing social values that relegated women to a position of inferiority.

In their written work, P_3 noted that “radioactivity was seen as a major innovation,” reinforcing the view of science as part of a modernization logic that blinded society to potential risks. P_{10}’s writing followed a similar path, mentioning that “society viewed the products as technological advances,” confirming the understanding that techno-scientific progress was legitimized by the public’s belief in innovation. P_1 also demonstrated an understanding that society at the time viewed radioactive products as fascinating symbols of progress: “The paint glowed; it was beautiful. People said it was good, that it was modern.” This same participant added that “people thought they were safe and even beneficial to one’s health.”

In their essay, participant P_{13} stated: “The public lacked information about the risks,” indicating an awareness of the role played by misinformation in that historical context. The perception that potential risks

were unknown also appears in the narratives of P_1 and P_2, who wrote, respectively, that “few knew about the dangers of radioactivity” and “The girls didn’t know anything. They just painted the dials.” However, these excerpts suggest that this lack of knowledge was not universal. Who were the “few” who knew about the dangers? The statement that the “girls didn’t know anything” implies that someone else did know. “The population lacked information about the risks” seems to indicate that the information existed but was not accessible to that public. These contributions offer an interpretation of the relationship between social ignorance and technical advancement.

In P_2’s oral contribution during the intervention, it becomes clear that, in his view, the industries were indeed aware of a great deal: “The industries wanted to sell. They didn’t warn anyone because they would lose money.” This statement demonstrates that the participant grasped aspects of the relationships between science, the economy, and commercial interests, showing critical awareness by recognizing that the omission of risks was linked to the preservation of corporate profit. P_5, in turn, stated in her written work that “the company had ignored warnings about the dangers of the paint,” indicating a perception that knowledge regarding the risks existed but was intentionally suppressed. The connection between the actions of the judicial system and corporate interests reinforces the idea of science as being embedded in power relations. “The justice system took a long time to adjudicate the cases,” the participant stated.

In his written piece, P_7 noted that “people trusted the safety of the products,” signaling a widespread social belief in scientific progress as something unquestionable. This point aligns with P_8’s statement: “It was only after several people died that they started investigating... before that, no one said anything.” This remark highlights a perception of science as a reactive practice, subject to social pressures and revisions based on tragic evidence, thereby revealing a non-linear conception of scientific development.

A combined analysis of the oral statements and written work reveals that several participants were able to perceive science as a social enterprise subject to political and economic interests, rather than as a neutral, objective activity. This understanding reinforces the effectiveness of the implemented proposal in fostering critical reflection within the context of science education. In this regard, these insights align directly with the critical view that science is instrumentalized by market interests, as discussed by Martins (2006), who highlights how technological choices are not neutral but are shaped by social and economic values.

Axis 2: Rendering invisible and gender inequality

The second thematic axis highlights the participants' ability to identify the historical marginalization of women through the case of the "Radium Girls." An analysis of the written work, cross-referenced with oral contributions made during discussions, reveals that participants showed sensitivity to how gender directly influenced the treatment of these workers by the USRC, the justice system, and the society of that era. Throughout the intervention, participants of both sexes demonstrated empathy for the workers' suffering and a critical awareness of gender inequality.

In their written response, participant P_3 stated: “They said we were making it up. That it was all just a 'weak woman' thing. But they were dying.” This excerpt highlights an understanding that the workers' pain was delegitimized by a society prone to dismissing complaints made by women. It reveals the internalization of a critical perspective regarding the silence of women's voices in contexts of institutional violence.

In their writing, participant P_{10} noted that “women were seen as cheap labor,” underscoring their vulnerability to workplace exploitation. This perception reflects an understanding of the precarious conditions imposed on the workers, linked to the inferior social status they occupied. Participant P_{12} wrote: “If they had been men, they would have obtained justice sooner,” indicating an awareness of the disparity in legal and social treatment based on gender. Meanwhile, participant P_{14} stated: “Society thought women were only good for marriage and housework; they weren't taken seriously even when they were sick,” highlighting the socially imposed stereotypes regarding women and their resulting invisibility.

These responses demonstrate the participants' awareness of how the workers' pain was delegitimized by a society prone to dismissing complaints made by women. Some participants identified gender inequality as a decisive factor in the prolonged suffering of the female workers and the delay in the institutional recognition of the issue. The inclusion of these reflections in the written responses reinforces the proposal's educational potential to foster a critical and sensitive perspective on gender relations.

During the discussions, participant P_6 expressed a similar view: “I also think, teacher, that it was because they were women, what lawyer was going to defend women who, in their eyes, were lying?” Here, the participant highlights the exclusion of women from spaces of representation and legal advocacy,

underscoring the intersection of gender and legal power. This statement brings to light the perception that gender status imposed real limits on the victims' ability to claim their rights. Other participants also clearly articulated their critical interpretation of the gender dynamics involved in the episode:

P_4: “They had no voice in society.” P_1: “Women had fewer rights at work.” P_9: “They were considered inferior in the labor market.” P_{11}: “They were viewed as less important in society.”

These contributions demonstrate that the participants recognized the naturalization of gender inequality, attributing part of the responsibility for the delay in the institutional recognition of the problem to women's social standing. They reveal a critical understanding that the way women were perceived at the time contributed to silencing and rendering the “Radio Girls” invisible. These oral and written excerpts highlight not only the participants' empathy regarding the suffering endured but also their understanding of the social mechanisms that perpetuate gender inequality. Thus, this theme demonstrates that the participants not only grasped the historical and scientific aspects of the episode but also managed to connect these understandings to broader social dimensions, particularly regarding gender inequality and the marginalization of women.

Analysis of the statements and written work reveals the participants' sensitivity in identifying the repercussions of gender inequality within this historical episode, indicating a certain level of maturity in their interpretation of social reality. Linking academic knowledge with the topic of gender allowed the participants to interpret the “Radio Girls” episode not as an isolated event, but as a reflection of oppressive social structures. It is essential to expand this discussion considering specialized literature. González García and Pérez Sedeño (2006) highlight that studies on science, technology, and gender reveal how scientific practice was historically marked by sexism and androcentrism, contributing to the exclusion of women and the delegitimization of their experiences. This exclusion is not limited to historical erasure but extends to the naturalization of social hierarchies that underpinned the marginalization of women. Along these same lines, Schiebinger (2001) emphasizes that science is not neutral regarding gender issues. Thus, by linking students' critical insights with the contributions of these studies, it becomes evident that the pedagogical inclusion of historical episodes relevant to gender issues can facilitate a critical reading of oppressive social structures, thereby fostering a more inclusive and emancipatory pedagogical practice. The participants' recognition that women were subjected to differential and unjust treatment based on gender marks a crucial step toward a form of science education that breaks away from apparent neutrality and moves toward an emancipatory pedagogical practice, as proposed by the 3MP framework. This type of perspective reinforces the potential of science education as a space for promoting citizenship and social justice. In particular, it aligns with arguments advocating the use of History, Philosophy, and Sociology of Science (HPSS) to make marginalized and historically excluded figures visible, mobilize knowledge and emotions, and encourage reflection on social justice and citizenship within science education, thereby fostering a critical stance regarding social inequalities (Silva & Moura, 2008; Schirmer & Sauerwein, 2014; Leal & Forato, 2021).

Axis 3: Ethical dimension and responsibility

In this thematic area, a key highlight is how participants engaged in reflection regarding the ethical implications of the "Radium Girls" case, revealing a critical understanding of the responsibilities held by companies, healthcare professionals, and legal institutions concerning the workers' experiences. Through their written work and classroom discussions, it was possible to identify the participants' perception of institutional negligence and the manipulation of scientific knowledge, demonstrating the development of a broader view of science as a situated social practice.

Several passages from the written assignments clearly express this understanding. Participant P_1, for instance, noted in their writing: “The doctors gave a different diagnosis... And because they were women, no one believed them.” Similarly, P_6 offered a critical perspective by stating: “The company knew about the danger but hid it. They hired doctors who lied in the medical reports.” This excerpt highlights the participants’ understanding of the direct responsibility borne by the company and its representatives in concealing the effects of radium. Meanwhile, P_{13} stated in their assignment: “They didn't want anyone to know that radium was harmful. So, they paid doctors to lie.” Here, one observes a clear interpretation of the link between economic interests and the manipulation of scientific knowledge.

These excerpts reveal the participants' perception of the use of false diagnoses as a silencing strategy, while also highlighting the intersection of gender inequality and institutional injustice. These accounts reflect an understanding that the agents involved made a deliberate attempt to conceal the truth, even in the face of the workers' evident suffering. Direct references to the falsification of diagnoses and the company's omissions demonstrate a critique of how medical and scientific authority was used to cover up the harmful impacts of radium. This type of critical analysis was also evident in oral contributions. During the discussions, P_6 stated:

“They knew it was harmful, but they hid it. They falsified the test results!” This sense of outrage was evident in other statements: P_6: “They worked in poor conditions and without protection.” P_9: “There were attempts to conceal the illnesses.” P_{11}: “The companies claimed ignorance of the danger.” P_{12}: “They hid many things from the painters.” P_5: “The justice system took a long time to adjudicate the cases.”

The indignation expressed in these remarks shows that the participants not only understood the historical context of the case but were also able to link it to fundamental ethical dilemmas, such as institutional responsibility and the right to information. These contributions reinforce the perception that the participants could identify the economic interests behind the concealment of health risks, as well as the strategic use of science (i.e., medical diagnoses) to protect institutions at the expense of human life. References to the actions of physicians, the manipulation of test results, and legal silence construct an articulate critique of how scientific knowledge can be mobilized to justify or conceal injustices.

Thus, this theme highlights the participants' ability to integrate scientific knowledge, historical analysis, and ethical judgment, recognizing that the omissions by the agents involved in the case were not accidental but systematic, and therefore demand a critical stance. By acknowledging the relationship between science, ethics, and power, the participants demonstrated a shift away from a view of science as neutral, adopting instead a critical and reflective perspective on the social impacts of scientific production. These results empirically reinforce the argument that historical episodes can offer valuable opportunities for developing a historical and social understanding of science and technology, allowing for a critical examination of the role institutions play in perpetuating inequalities and omissions (Silva & Moura, 2008).

Bringing these reflections into the school environment contributes to shaping individuals who understand science and technology as human practices, permeated by values and interests, that must therefore be constantly guided by ethics and social responsibility. This perspective aligns with the proposal of Forato and other authors (2012), who argue that science education should go beyond conceptual content and address the ethical dimensions of scientific practice as an essential component of citizenship education.

Axis 4: Provisional nature and transformation of scientific knowledge

This theme reveals that participants were able to perceive science as a historical construct, one that is mutable and dependent on the social and technological context in which it exists. The understanding that scientific knowledge is subject to change over time, as new evidence and experiences emerge, was clearly expressed in some written work and oral contributions.

In her written response, participant P_5 noted: “At first, everyone thought it was good. But over time, people started getting sick. That was when they realized radium could be harmful.” This excerpt highlights the assimilation of the idea that scientific knowledge is socially and historically constructed and can be revised considering new situations and discoveries. The statement also marks a contrast between the initial optimism regarding radioactivity and the subsequent recognition of its harmful effects. Complementing this, participant P_2’s written response offers another example: “They established certain precautions regarding the use of radioactivity.” Here, the participant demonstrates an understanding that science-related practices also evolve over time, keeping pace with advances in the understanding of the risks and benefits involved.

Other written excerpts reinforce this collective understanding. Participant P_{11} stated: “The public didn’t have information about the risks,” while participant P_6 wrote: “Few people knew about the dangers of radioactivity.” These records reveal a perception that scientific knowledge was restricted to certain groups and that the dissemination of this knowledge occurred progressively, based on new evidence. Participant P_{14}’s response highlighted: “The girls didn’t know anything; they just painted the hands [of the dials],” illustrating the workers' lack of awareness regarding the risks and their lack of access to reliable scientific information.

During oral discussions, the students also demonstrated an understanding of the provisional nature of science. Participant P_{11} stated: “It was only after several of them died that they started investigating... before that, no one said anything.” This statement articulates the view that science acted reactively in this episode, pressured by the consequences to revise its positions. This perception also emerged during the discussion on the Cesium-137 accident, specifically during the initial problem-posing stage, when participant P_{14} remarked: “It was only when the first accident happened that they started to realize it was harmful.” This comment highlights the understanding that scientific knowledge is often triggered or reformulated, demonstrating its provisional nature. Furthermore, during the interactions, participant P_6 noted: “Science got it wrong at first but fixed it later.” This phrasing encapsulates the understanding that scientific knowledge is constructed through trials, successes, errors, and revisions, remaining always open to transformation.

These statements demonstrate that the participants did not view science as the possessor of absolute, unquestionable truths; instead, they indicated that such knowledge is subject to change. The conception of science as provisional and constantly evolving emerged significantly. This understanding is central to the Nature of Science (NoS) approach, particularly regarding the perception of science as a non-linear process subject to controversies and reconstructions (Gil-Pérez et al., 2001; Azevedo & Scarpa, 2017). By linking the consequences of radium use to the shift in stance by scientific and medical institutions, the participants demonstrate a critical reading of knowledge construction—aligning with Martins (2015), who asserts that scientific education must incorporate historical, epistemological, and social dimensions.

Axis 5: Social justice and critical stance

The fifth axis highlights how participants were moved by the injustices experienced by the Radium Girls, stirring up feelings of outrage, empathy, and a desire for social redress. Throughout the written work and discussions, a critical perspective emerges regarding the relationship between science, power, and justice, marking a significant step forward in developing a civic stance on the social impacts of science.

In the written responses, indignation at the institutional negligence was clearly expressed. Participant P_9, for instance, noted: “They wanted justice. They wanted others to know that radium was making people sick.” This statement reveals a keen understanding of the case's ethical and political dimensions, acknowledging both the workers' suffering and the importance of sharing this knowledge, as an act of speaking out and fighting for recognition. Also, in the written phase, P_{10} stated: “They only cared about sales, not the women. That is very wrong.” The participants demonstrated critical awareness by identifying profit as the priority for the institutions involved, at the expense of the workers' health and dignity. Here, an ethical judgment condemns the market-driven logic that governed corporate decisions. Another relevant example appears in P_8’s text, which observed: “Safety measures regarding the products were adopted after the death of a wealthy man in the USA.” This sentence reveals an implicit critique of the selectivity of protection and redress policies, suggesting that an effective response occurred only after the death of a socially valued individual. This indicates the participant's ability to link the episode to structural inequalities affecting those with, and without, visibility and power.

During the discussions, this sense of justice was also voiced by participants: P_{13}: “The women were forgotten. They suffered, and for a long time, no one did anything”; P_6: “The justice system took a long time to rule on the cases”; P_9: “No one helped them; it seemed like it didn’t matter”; P_{10}: “They wanted justice. They wanted others to know that the radium was making them sick”; P_7: “They only cared about sales, not the women.” These statements indicate an emotional and cognitive involvement that transcends factual content, revealing that the participants not only learned about the case but also interpreted it through the lens of ethical values and principles of equity and human rights. This type of engagement aligns with the observations of Leal and Forato (2021), who highlight the potential of the Radium Girls case as a pedagogical narrative capable of bridging science and citizenship, fostering discussions on rights, historical redress, and the primacy of human life over economic and political interests.

By recognizing the injustices suffered by the workers, the participants expressed the view that science, far from being neutral, can be used both to foster emancipation and to perpetuate inequalities. Thus, this aspect demonstrates that the pedagogical practices employed allowed participants to experience scientific knowledge not as something isolated or purely technical, but as part of symbolic and material struggles with real-world consequences for human lives.

6. CONCLUSION

The empirical investigation carried out demonstrated that the participants were able to mobilize historical, ethical, and social knowledge from reading the historical-pedagogical narratives and classroom discussions. Significant understandings were achieved regarding science as a social construct, subject to economic and political interests, in addition to reflections on gender inequality, labor rights, scientific responsibility, and the communication of knowledge. The voices of the participants, both in written productions and in classroom discussions, revealed different levels of appropriation of the explored content, ranging from the assimilation of technical aspects, such as the effects of radioactivity, to reflections on institutional negligence, gender inequality, the provisional nature of scientific knowledge, and social justice.

The results obtained show that the participants, in a relatively satisfactory way:

- Understood science as a practice situated within historical, ethical, and social contexts, far removed from the notion of neutrality and absolute truth;
- Recognized gender inequalities and the processes that systematically render women invisible;
- Identified the relationships between science, the economy, and power, grasping the institutional interests behind the omission and manipulation of scientific discourse;
- Demonstrated empathy, indignation, and a sense of justice—elements fundamental to developing a critical mindset and a sense of civic engagement.

The analysis of written productions compared with oral contributions indicated that the didactic sequence not only contributed to the learning of aspects related to radioactivity but also promoted the formation of a more critical and humanized view of science. The “Radio Girls” episode proved, in this sense, to be a powerful resource for discussing cross-cutting themes and promoting scientific literacy in a contextualized way. We understand that initiatives like this contribute to overcoming content-based and decontextualized approaches to science teaching, bringing students closer to a broader and civic understanding of science.

It is important to highlight, however, that some limitations of the study need to be recognized. The intervention was carried out in a 9th year elementary school class, which restricts the possibility of generalizing the results to other school contexts. Furthermore, the time available to apply the didactic sequence limited some discussions. Another aspect to consider is the fact that the researcher also plays the role of teacher responsible for the class, which may have influenced the dynamics of interactions and the conduct of activities. Recognizing these limitations does not diminish the relevance of the findings but reinforces the need for new investigations in different contexts and school grades, to broaden the understanding of the teaching potential of HFC.

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