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ARTICLE

THE MARIE CURIE CASE THROUGH THE CULTURAL HISTORY OF SCIENCE: DISCUSSING RELATIONS BETWEEN WOMEN, SCIENCE, AND PATRIARCHY IN SCIENCE EDUCATION

Natasha Obeid El Jamal[1]
https://orcid.org/0000-0002-5988-7158

Andreia Guerra[1]
https://orcid.org/0000-0002-6397-3817

ABSTRACT:

This study was developed from the perspective that science education must overcome teaching that focuses on scientific concepts, moving towards critical science education connected with the current political issues, as the relations between science and patriarchy. Marie Curie is a recurrent example in the literature of a woman in science. From this, we develop a study to answer the question: what conditions enabled Marie Curie to participate in science, and how the understanding of these conditions allows discussions in science education about the low occurrence of female examples in the history of science. Based on the Cultural History of Science approach and references from science education, the results indicate that discussing female scientist examples is insufficient to a female representation in science. The visibility of women in science is linked to the conditions to participate in scientific practices. Therefore, the structural conditions need to be expanded to have more women doing science.

Keywords:
Women in science;
Patriarchy;
Science education.

O CASO MARIE CURIE PELA LENTE DA HISTÓRIA CULTURAL DA CIÊNCIA: DISCUTINDO RELAÇÕES ENTRE MULHERES, CIÊNCIA E PATRIARCADO NA EDUCAÇÃO EM CIÊNCIAS

RESUMO:

A pesquisa aqui apresentada foi construída na premissa que a educação em ciências deve superar um ensino voltado à aprendizagem de conceitos científicos, indo em direção a uma educação crítica e conectada com questões políticas da modernidade, como as relações entre ciência e patriarcado. A partir da recorrência na literatura de Marie Curie como exemplo de mulher na ciência, desenvolvemos a pesquisa com vistas a responder a seguinte questão: quais condições possibilitaram Marie Curie a participar da ciência e como a compreensão dessas condições permite caminhos na educação em ciências capazes de promover discussões a respeito dos baixos números de exemplos femininos na história da ciência. Com base em referenciais da educação em ciências e da História Cultural da Ciência, construímos subsídios para responder à pergunta de pesquisa, apontando que trazer exemplos de mulheres na ciência é insuficiente para uma suposta representatividade feminina. Isso porque a visibilidade de uma cientista depende de suas condições de participar das práticas científicas e, portanto, para termos mais mulheres na ciência, as condições estruturais para elas trabalharem devem ser ampliadas.

Palavras-chave:
Mulheres na ciência;
Patriarcado;
Educação em ciências.

1 Centro Federal de Educação Tecnológica Celso Suckow da Fonseca (CEFET), Rio de Janeiro, RJ, Brasil.

EL CASO MARIE CURIE A TRAVÉS DEL LENTE DE LA HISTORIA CULTURAL DE LA CIENCIA: DISCUTIR LAS RELACIONES ENTRE MUJERES, CIENCIA Y PATRIARCADO EN LA EDUCACIÓN CIENTÍFICA

RESUMEN:
La investigación presentada se fundamentó en la premisa que la educación científica busca superar una enseñanza orientada hacia el aprendizaje de conceptos científicos, avanzando hacia una educación crítica y conectada con las cuestiones políticas modernas, como las relaciones entre las ciencias y el patriarcado. Partiendo de la recurrencia en la literatura de Marie Curie como ejemplo de mujer en la ciencia, desarrollamos una investigación con miras a contestar a la siguiente pregunta: qué condiciones permitieron a Marie Curie participar en la ciencia y cómo la comprensión de estas condiciones permite trazar caminos en la educación científica que estimulen las discusiones sobre el bajo número de ejemplos femeninos en la historia de la ciencia. Basados en referencias de la educación científica y la Historia Cultural de la Ciencia, construimos soportes para contestar la pregunta de la investigación, señalando que utilizar ejemplos de mujeres en la ciencia es insuficiente para una supuesta representatividad femenina. Esto porque la visibilidad de una científica depende de sus condiciones para participar en las prácticas científicas y, por lo tanto, para que haya más mujeres en la ciencia, se deben ampliar las condiciones estructurales para que puedan trabajar.

Palabras clave:
Mujeres en la ciencia;
Patriarcado;
Educación científica.

INTRODUCTION

Science education promotes critical thinking about science and society (Hodson, 2010; El Jamal & Guerra, 2020; El Jamal, 2021). This critical perspective, based here on Hodson and Wong (2017), and Rudolph and Horibe (2016), suggests that it is necessary to go beyond science teaching strategies aimed solely at learning scientific concepts, moving towards teaching connected with contemporary political issues, such as those related to women's participation in science. Therefore, this research defends a more politicized approach to science education that considers the relationship between the exploitation/domination of subjugated groups and science to provide a critical perspective on the relationship between science and patriarchy and sociopolitical action (Hodson, 2010; El Jamal, 2021).

The results of the bibliographic research performed by Prado and Rodrigues (2019) and El Jamal and Guerra (2020) motivated the present research and this look at science education. Prado and Rodrigues (2019) and El Jamal and Guerra (2020) analyzed how the participation of women in the History of Science (HoS) is addressed in journals aimed at teaching chemistry. Even focusing on different journals and in different decades, the two surveys identify few references to the participation of women in science. The results of El Jamal and Guerra (2020) show that of the 51 articles that highlight the work or trajectories of scientists, only 11 refer to a female scientist. Also, Marie Curie is a recurring name. She is highlighted as the first and only woman in many facts surrounding the history of science and an actual example to encourage young women to interact with the world of Science (Owens, 2009; El Jamal & Guerra, 2020).

These results recall Schiebinger's (2001; 1989) defense that using examples of exceptional women to encourage women's participation in science is insufficient. This path ends with suggesting that incentives for women are enough to reverse the problem of their low representation in science, ignoring the disproportionate number of women scientists compared to the number of women who would seek to do science but are outside the field. Schiebinger (2001) also indicates that these exceptional examples do not reveal how the absence of women in science is related to patriarchy, nor how changes in the structure of scientific institutions are necessary for the situation to change.

Marie Curie, for example, won the Nobel Prize in 1905 and 1911, but that did not open doors for women in HoS. This fact is evident in her recidivism and the absence - or in the deferral - of other women in the bibliographic research carried out by Prado and Rodrigues (2019) and by El Jamal and Guerra (2020). Nevertheless, the Nobel Prize and other factors in Marie Curie's trajectory gave the scientist notoriety even outside the academic world. For example, she was featured in media in the early 20th century, which contributed to the consolidation of her image (Quinn, 1997).

Reflecting on this, the present authors suggest that Marie Curie is a "visible" woman in science, and her visibility signals, in an analogous way, the invisibility of other women. Therefore, it is essential to discuss what can be learned from these examples of exceptional women in science. Connected to this, the recurring example of Marie Curie, identified by Prado and Rodrigues (2019) and by El Jamal and Guerra (2020), suggests that this case is present in science education and that Brazilian teachers and students know the scientist well. This notoriety led to using her career as an example to examine her exceptionality since discussing Marie Curie's visibility can reveal the necessary conditions for female scientists to participate in scientific practices. Conversely, it can suggest that the absence of these conditions excludes a vast majority of women historically from science. Therefore, the present study was conducted in light of the historiographical aspect of the Cultural History of Science (CHoS) on the Marie Curie case to answer the following question: what were the conditions that enabled Marie Curie to participate in science, and how can understanding these conditions guide science education that promotes discussions about the low numbers of female examples in HoS?

The CHoS historiographical lens, discussed in the next section, considers scientific practice as one category of analysis, understanding science as culture (Pimentel, 2010). This historiographical lens was chosen to reflect the contextual and local conditions for Madame Curie's success by focusing on the scientific practices that were part of her trajectory and the elaboration of radioactivity. In general, introducing students to issues about women in the history of science needs to combine social, historical, and cultural factors with an understanding of the nature of science and scientific work through the theoretical lens of the CHoS (Moura & Guerra, 2016).

The article is divided into four sections that respond to the proposed objective. The first section describes the theoretical foundation of CHoS and how this historiographical lens helps us establish relationships between science and patriarchy. The second section will investigate some historiographical aspects of Marie Curie's trajectory, the elaboration of radioactivity, and the relationships between the scientific practices of institutionalization, circulation of knowledge, and experimentation. The third section discusses the results of this investigation and how these results can inspire pathways in science education aimed at training students who are critical of science and patriarchy. Finally, articulations between the Marie Curie case and science education in Brazil are identified. The article concludes with some final remarks.

PATRIARCHY AND CULTURAL HISTORY OF SCIENCE IN EDUCATION

In science education, Brickhouse (2000; 1994) and Carlone et al. (2015) suggest that questions regarding the participation of women in science are related to how women's identities overlap (or not) with scientific identities. The work of Carlone et al. (2015) suggests that women feeling represented by individuals who do science and women recognizing themselves as scientific people are elements that influence choices for a scientific career. In these works, identity is recognized as something fundamental to understanding the participation of women in science. However, as Harding (2015) highlights, the limited presence of women in science is also a result of the structural issues in which science is historically co-produced.

These questions, combined with a perspective on science education that proposes critical understandings of science and society (El Jamal, 2021), led to the historiographical choice of the CHoS for the research on the Marie Curie case. According to Pimentel (2010), the historiography of CHoS is derived from the New Cultural History in the 1980s. It disregards exclusively textual historical narratives focusing on individual scientists and theories in favor of more dynamic history, including contextual and cultural conditions and places for the production of science, more specifically, for the study of scientific practices.

The sources with which CHoS works vary, such as scientific and newspaper articles, letters, diaries, scientific expedition reports, scientific images, and documents from scientific institutions. The cultural historian of science studies scientific practices from these diverse sources, which are understood here as a web of actions, negotiations, and social relations that constitute science and sustain scientific activity (Burke, 2008). Experimental practices, medical practices, observation practices, dissemination practices, and migration practices are all components to describe scientists' behavior, their context, and forms of knowledge production (Pimentel, 2010).

Forms of production and communication of scientific knowledge, its means of representation, and the social and cultural context of its production are all significant when it comes to the area of scientific practice. Therefore, the CHoS includes recurring themes within cultural and social studies (Burke, 2008), enabling the option of analyzing scientific practices and intermingling themes, such as themes of gender, body and sexuality, race and ethnicity, and history and memory (Pimentel, 2010).

This historiographical line allows discussion of the participation of women in the development of science. Furthermore, the CHoS helps understand that science and society co-produce each other. Thus, CHoS supports that science was built under a patriarchal structure, revealed in an epistemology that carries a contaminated view of gender, reflected in the invisibility of women in the field (Harding, 2015; Nyhart, 2016).

To establish the relationship between science and patriarchy through the lens of CHoS, it is also necessary to argue about the regime of patriarchy. According to Saffioti (2015), patriarchy is the regime of domination/exploitation of women by men. According to Cordeiro (2020), the family is the sociological pillar of patriarchy since, within the family, members are co-opted to perform social roles within the patriarchal society. However, patriarchy spreads across the family, society, and the state. Furthermore, despite focusing on the difference between the sexes, patriarchy also encompasses issues of race and class in political relations; that is, women are in a condition of domination/exploitation whether by gender, race, or class (Saffioti, 2015). This exploitation happens because loose ties between patriarchy, racism, and capitalism, the triad that the author calls substructures in the global structure, create contradictions in the historically constructed reality.

According to Saffioti (2015), patriarchy is the longest-lived political system in humanity, covering the most recent six or seven millennia of history. Despite being long-lived, patriarchy has morphed throughout history as power structures changed and intensified. According to Saffioti (2015), "in fact, like other social phenomena, patriarchy is also undergoing permanent transformation" (p.48). Patriarchy, a regime co-opted by the capitalist regime, circulates widely and ideologically, perpetuating it over the years (Cordeiro, 2020). Furthermore, although the subordination of women to men manifests in different ways according to time and place, "[...] the nature of the phenomenon, however, is the same. It presents the legitimacy that its naturalization attributes to it" (Saffioti, 2015, p.107). Thus, the Marie Curie case and the absence of other women in science can be understood as reflections of the continuously maintained patriarchy.

In patriarchy, economic inequality between men and women widens with the institutionalization of education, and women are excluded from the beginning of this process (Cordeiro, 2020). In Europe, women only had broad access to higher education from the end of the 19th century onwards (Schiebinger, 2001). Women's lack of freedom was maintained and persisted with the advance of capitalism, causing women's civil and economic inequality concerning men (Saffioti, 2015). Female education was a form of women's emancipation since attachment to a man's authority was essential for the wife's survival.

In this sense, there is an inseparable relationship between patriarchy and the world of work (Saffioti, 2015; Federici, 2019). The predominance of private activities was allocated to the family sphere and public activities to the state sphere. With the sexual division of labor, women were held responsible for work in the private sphere, while men for work in the public sphere. Saffioti (2015) explains that a society based on a patriarchal regime constructs male and female genders with roles assigned to each one, in the public and private spheres, respectively.

This relationship of patriarchy with the world of work reflects women's participation in science. Schiebinger (2001; 1989) points out that in the 19th century sexual characteristics took on a new meaning in determining who would or would not do science. In this same context, what Schiebinger (2001) calls the "professionalization of science" takes place in Europe. The professionalization of science is concomitant with the polarization of the public and domestic spheres, placing work in science within universities, industries, and academies of science. While the family remains in the private domestic sphere, science has migrated to the public sphere. If women participated in science throughout the 18th century in Europe, they did so at home (Opitz, 2016; Schiebinger, 2001).

The entry of science into public spaces in the 19th century made it difficult for women to access science since broad access to universities, laboratories, and other scientific institutions had many restrictions (Schiebinger, 2001). Among the difficulties, the main one involved the work of social reproduction, which was out of step with the institutionalization of education and science (Schiebinger, 2001). Moreover, with science in the public sphere, women faced many obstacles to participating in scientific practices because gender made them responsible for the private sphere. Marie Curie at the University of Paris-Sorbonne is among the few women who were seated in European universities in the late 19th and early 20th centuries.

The study of scientific practices in light of CHoS can help introduce the theme of women in science to science education, understanding science as a co-product of a patriarchal society (Harding, 2015). Studying scientific practices as cultural practices can reveal how science was constructed and to whose benefit or detriment (Nyhart, 2016). Discussions about how political, social, cultural, and economic factors can align themselves in the domination/exploitation of women in science are made possible (Harding, 2015; Saffioti, 2015).

The historiography of the CHoS is, therefore, a political choice, in the sense that this approach does not lend itself to boastful discourses, and the individual scientist is not central but proposes to analyze the scientist's surroundings based on the ongoing study of scientific practices. The next section returns to the discussion of the CHoS through reporting the results of historical research on the trajectory of Marie Curie. With this, we will discuss some conditions that led women to recognition, that is, to visibility as scientists in a patriarchal society.

The historiographical contribution of the CHoS suggested a microhistorical study, focusing on the analysis of scientific practices established during the emergence of radioactivity in Marie Curie's trajectory. From the works of Pugliese (2012) and Quinn (1997) on Curie herself and of Martins (1998a; 1998b) on radioactivity, the historical episode is examined. This panorama and recognizing that the scientist lived and worked in France suggested a list of three practices in that context: the institutionalization of female education in France, the circulation of people and knowledge, and experimentation. After defining the scientific practices to be explored, primary sources were gathered, such as the speeches of Marie Curie and Pierre Curie receiving the Nobel Prizes in 1903 and 1911, the articles published by Marie Curie and Henri Bequerel, and Madame Curie's diary reproduced in the work of Monteiro (2019). In addition to the works of Pugliese, Quinn, and Martins, secondary sources were gathered, such as the works of Weisz (1983), Picard (2010), Moulinier (2002), Sigrist (2009), and Mayeur (2007) to study the institutionalization of female education in France. Finally, the works of Livingstone (2003), Fyfe (2016), Opitz (2016), and Kirby (2016) were used to synthesize the circulation of people and knowledge and experimentation.

The question and microhistorical outlook that guided the research led to discussions of the patriarchy and the participation of women in science, based exclusively on the Marie Curie case. Thus, based on the analyzed sources, it is impossible to compare the training of one scientist and that of South American women in their context. However, by focusing on this one particular context, the established power relationships can be addressed more precisely and patriarchy and science more generally.

SCIENTIFIC PRACTICES AND THE CASE OF MARIE CURIE

This section addresses the research on the Marie Curie case in light of the historiographical lens of the CHoS, from three subsections that deal with practices relevant to the research question: the institutionalization of female education in France, circulation of scientific knowledge, and experimentation.

Institutionalization of female education in France XIX

Studying the institutionalization of female education in France in the 19th century suggests that the entry of women into universities was a gradual and slow process in that context (Weisz, 1983). At the end of the 19th century, when the number of female enrollments in French higher education began to grow, women sought more courses in arts and letters (Weisz, 1983). In this context, Marie Curie arrived at Paris-Sorbonne.

Curie's birth name was Maria Salomea Sklodowska (1867-1934), and she was born in Warsaw, the Polish capital that was part of the Russian Empire. From 1772 to 1795, Polish territory was divided between the Kingdom of Prussia, the Russian Empire, and Austria (Pugliese, 2012). Therefore, Maria Sklodowska lived in Poland as a colony, which regained its independence only at the end of World War I, in 1918, when she was already in France.

Her father, Wladislaw Sklodowski (1832-1902), was a professor of physics and mathematics, and her mother, Bronislawa Sklodowska (1835-1878), was headmistress of a girls' school. Both were involved in science teaching and had home laboratories for their teaching activities (Quinn, 1997). Marie, who was already stimulated by science at home, was the best student in her class at school. At age 15, she finished first in all subjects. However, in Poland, taken over by the Russians, women were only able to attend the "flying universities," which were clandestine universities attended chiefly by women who dreamed of continuing their studies at the few universities abroad that accepted them (Pugliese, 2012). Marie Curie began her scientific studies at Flying University, which operated from 1885 to 1905 in Warsaw under the control of the Russian Empire (Quinn, 1997).

At the age of 24, intending to continue her studies, Maria Salomea Sklodowska left for Paris, following her older sister Bronislawa Dluska (1985-1939) to study physics and mathematics at the Paris-Sorbonne University (1971-2017), formerly part of the University of Paris IV (Pugliese, 2012). Maria Sklodowska had help from her father to migrate to France and enroll at the university, even with limited resources. In Paris, as in Poland, she worked as a governess to finance part of her studies (Quinn, 1997).

Before renting an attic near the Latin Quarter, a neighborhood home to many students and intellectuals because it was close to the University of Paris, Maria Sklodowska lived with her sister and brother-in-law. In 1893, she graduated in Physics, Chemistry, and Natural History and began to work in the industrial laboratory of her teacher Gabriel Lippmann (1845-1921). Meanwhile, with the help of a scholarship offered to international students of excellence, she took a second degree at the Sorbonne, in mathematics, which she completed in 1894.

In the year she began her scientific career, she met Pierre Curie (1859-1906). Their interest in the natural sciences brought the couple closer. Pierre was a professor at the Paris School of Industrial Physics and Chemistry . They were introduced by the Polish physicist Józef Wierusz-Kowalski (1866-1927), who had heard that Maria Sklodowska was looking for a laboratory to carry out her work and thought that Pierre could help her. Although Pierre did not have a large laboratory, he made space available for Maria (Pugliese, 2012).

Maria Sklodowska, in July 1895, married Pierre Curie, changing her name to Marie Curie. The name change arising from the marriage, according to Pugliese (2012), put her in a different position. The Poles did not have the same prestige as the French in universities and scientific spaces. Despite Madame Curie's accent, her new surname sometimes concealed her Polish origins and, at other times, annoyed eugenics patriots (Pugliese, 2012). Her marriage to Pierre Curie played a vital role in her "Frenchization" and her introduction into the academic environment. Pierre was a man and had significant social relationships in the academic world (Pugliese, 2012).

In 1896, already married, Marie Curie acquired a certificate to teach classes in girls' secondary education (Quinn, 1997). Despite the limits on what women could learn, the institutionalization of female education in France was a great novelty (Quinn, 1997). The new schools aimed at female education sought teachers from the great French universities and faculties (Weisz, 1983). Marie Curie was the first woman to join the faculty of the school of Sèvres (Quinn, 1997), a public secondary school for girls, founded in 1881 at the beginning of the Third Republic (1870-1940) (Quinn, 1997).

In the context of Marie Curie, the education of women in 19th century France was directly related to the politics of the Third Republic. There was a great movement of the republican regime to take education away from the influence of the Catholic Church. Higher education had a role in elite training, and Catholic secondary education produced elites with social and political views considered opposed to the regime (Weisz, 1983). In this way, the republicans committed their efforts to secularize education. As female secondary education was the church's responsibility until then, it was the first target of the secularization of secondary education.

Until then, primary and secondary education were solidly religious due to the Falloux Act of 1850, requiring all educators to include catechism in the curriculum and take students to Mass (Weisz, 1983). However, as already mentioned, with the beginning of the Third Republic, the leaders of the new regime wanted educated citizens and proposed to exclude religion from education. Thus, on December 21, 1880, the Camille Sée law was passed, which established access to public secondary education for girls, and the course in religion was replaced by courses in morals (Mayeur, 2007). In this context, in 1881, the creation of the Escola Normal Superior de Sévres was approved to train female teachers for secondary schools.

With the Camille Sée Act, the Republicans had no intention of bridging the intellectual gap between the two sexes, as the curriculum for girls excluded the humanities and classical philosophy and had no intention of preparing them to enter universities (Mayeur, 2007). For advocates of the new system, the real issue was political: public secondary education for women wanted a secular education for mothers-to-be and thus to keep children's education away from clerical influence. Women's education in the Third Republic was neither egalitarian nor emancipatory; it was secular (Mayeur, 2007). However, establishing a secondary education system for girls in 1880 was a game-changer because it produced a ready clientele for universities.

Until the turn of the 19th to the 20th century, the presence of women in all French universities was low regardless, never exceeding 3% of the total number of students (Weisz, 1983). Moreover, most of the students in this small group were part of the humanities courses (Weisz, 1983). On the other hand, students who sought science courses, in general, continued their studies until their doctorate and, as a reflection of that patriarchal society, very few women stayed so long at the university and away from the private sphere (Schiebinger, 2001).

This percentage of female students was primarily made up of foreigners who came to France searching for a university education, which was inaccessible in their country or attracted by the prestige of the cultural metropolis (Sigrist, 2009). Maria Sklodowska was one of these international students; she was part of a group of 23 women among 2,000 students enrolled at the Faculty of Science at the University of Paris-Sorbonne in 1891, a decade after the Camille Sée law was passed (Quinn, 1997).

The University of Paris accounted for almost half of female enrollments in French higher education, frequented by foreigners of both sexes (Sigrist, 2009). Picard (2010) highlights that scientific knowledge was centralized in the French capital. Universities outside the capital were less recognized. Thus, most of the French scientific production centered around Paris and had made the metropolis much more visible (Picard, 2010).

For Marie Curie's successful trajectory, therefore, being at the university center of the capital played a role. Those who wanted a scientific career could try their luck in the capital for many reasons; the Sorbonne has an eminent faculty, and students could continue living in the capital after graduation (Weisz, 1983; Picard, 2010). The Sorbonne faculty, in particular, was made up of professors from large research institutions and had contact with the international scientific community. It is also noted that Marie Curie obtained the most coveted diploma in Science, the single diploma in Physics, Chemistry, and Natural History (PCN), instituted in 1893 at the Paris-Sorbonne.

The way students enter the University of Paris-Sorbonne has taken place in different ways throughout the institution's history. During most of its history, the university required the payment of annual fees and entrance fees, in addition to the completion of competitive exams (Weisz, 1983; Picard, 2010). Although, from the 1800s onwards, secondary education was free for girls and higher education offered scholarships for French nationals and foreigners, entering higher education required certain material conditions, such as costs related to migration and housing. Thus, it is important to note that Marie Curie obtained a scholarship, which was necessary to complete her second degree in Mathematics (Quinn, 1997).

Regarding the profile of students from the , the majority were bourgeois males, although the female gender has gradually imposed itself (Moulinier, 2002). In this context, Marie Curie joined the Sorbonne in 1891 and, after living with her sister, rented a neighborhood attic apartment. Due to housing costs in the capital, she spent three years in poorly heated rooms in winter, saving and studying intensively (Quinn, 1997). The high housing costs in the neighborhood closest to the Faculty of Sciences indicate how much material conditions are necessary for scientific practice.

The French higher education system between 1863 and 1914 was entirely peripheral to the majority of the population, preferentially serving the wealthiest social groups (Weiz, 1983). Moreover, the best research institution was located in the capital, making education inaccessible to the lower classes who lived far from Paris. In short, high educational standards were associated with the upper classes of society (Weiz, 1983).

Given the elitist profile of French higher education at the time, the difficulties of women entering scientific careers are not only justified by the norms of the female gender imposed by patriarchy but also by the economic inequalities imposed by capitalism, which highlights the relationship between patriarchy and capitalism identified by Saffioti (2015). In the context in which the Faculty of Sciences of Paris-Sorbonne trained students, who were primarily men of affluent social classes, Marie Curie became the first woman to obtain a doctorate from the Paris-Sorbonne. The practice of institutionalizing female education in France involved in the Marie Curie case refers to legitimizing female education in that location, considering that she is part of a select group of women in the Faculty of Science (Quinn, 1997).

Circulation of people and scientific knowledge

For the Marie Curie case study, it is essential to pay attention to the circulation of people and scientific knowledge in that context. Despite the expansion of female education, french men continued to constitute the largest group of university students for a time. Nevertheless, french universities were quite successful in attracting international students, and French women fought for changes in the structural conditions of that society, allowing the numerical advantage of French men over the two new categories of students – women and foreigners – to decrease during the 20th century (Sigrist, 2009).

At the end of the 19th century, there was considerable opposition to the admission of women and foreigners to German universities. However, enmity with Germany and the French defeat in the Franco-Prussian War motivated France to invest in education at all levels and receive foreigners without restrictions. Scholarship programs in 1877 and 1881 for international students were established at the Sorbonne to coordinate all activities in this sphere (Weisz, 1983).

Weisz (1983) points out that university migration to France contributed to the establishment of elites in their countries of origin. Concerning the female component of these migratory flows, mainly students from Eastern Europe, notably the Russian Empire, mostly make up this group. The political and social conditions of the colonial countries in Eastern Europe, including the ban on female higher education, were mainly responsible for the large-scale influx of students to France (Weisz, 1983).

As a result of this movement, during the 1893 academic year, French universities received 83% of their total number of international students from the Russian Empire (Weisz, 1983). However, historical accounts of Russian students in France include only a few works, mainly focusing on males and higher technical education establishments (Sigrist, 2009). In this case, the trajectories of students from the Russian Empire in France remain, in many ways, unknown, except for those who, like Marie Curie, gained visibility after university life.

The statistical research carried out by Weisz (1983), entitled Women Students in Universities, allows a closer examination of the female population in French universities. Between 1902 and 1914, the proportion of women in French universities increased from 3.6% to 10.1%, while French enrollment only increased from 2.2% to 6.1%. Weisz (1983) also shows that the number of women enrolled in science increased with the growing number of female international students in France. Marie Curie was part of this migratory contingent from the Russian Empire to France.

Migratory flows from Eastern Europe to France consisted of women seeking opportunities to attend higher education in a country where female education was allowed. International students attended the University of Paris due to the international prestige that the institution in the capital had gained. However, women looked more for courses in Letters and Arts than for science. According to Shiebinger (2001), women found it more challenging to participate in science in the public sphere from the 19th century onwards. According to Perrot (2006), in 19th century France, women withdrew from public spaces and focused more on private female/family spaces.

According to Shiebinger (2001), women who wanted to pursue scientific careers had two options with the increasing professionalization of science. First, they could try to follow the path of public instruction and certification through the universities, like their male counterparts. Unfortunately, this pathway was not available until the 20th century. Alternatively, they could continue to participate as assistants in the (private) family sphere, each increasingly invisible from scientific husbands or brothers. For example, Marie Curie, a Polish scientist who studied at the Paris-Sorbonne in the late 19th century, achieved fame despite having shared scientific recognition with her husband at many awards and in the university's laboratories (Schiebinger, 2001).

The circulation of knowledge also occurred by disseminating and awarding scientific research through scientific societies that spread throughout Europe (Livingstone, 2003). Concerning the Marie Curie case, according to Livingstone (2003), there was a profound "influence of geography on the production of scientific knowledge and its movement around the world" (p.137). The geography of knowledge was centered on countries like England, France, and Germany. According to Fyfe (2016), three languages dominated scientific publications at the beginning of the 20th century: English, French, and German.

Publications allowed knowledge to circulate from one country to another (Livingstone, 2003; Fyfe, 2016). For example, these publications circulated information on X-rays from Germany to France, arousing the interest of other researchers, such as Henri Becquerel (1852-1908), Pierre Curie, and Marie Curie, allowing new fields of study and new results in science. In addition, the centrality of some European countries concerning communication networks between scientists and the dissemination of scientific knowledge caused the notoriety and advancement of specific scientific research.

Studying X-rays, Becquerel found new results regarding uranium rays. In early 1896, he presented the first results of his research at the Academy of Sciences in Paris. Becquerel (1896) ended his communication of May 18 with the indication that uranium was "the first example of a metal that presents a phenomenon on the order of an invisible phosphorescence" (p. 1088). The scientist suggested that uranium compounds emit radiation even when not exposed to light in the same communication.

Becquerel's research on uranium rays was the starting point for Marie Curie's research. Curie intended to make the results of her experiments public. However, only men and members of the Paris Academy of Science could present their work publicly (Quinn, 1997). In the 19th century, successful journals were in the hands of influential editors with editorial skills in academia; moreover, both editors and authors of scientific journals were men (Fyfe, 2016).

Marie Curie could only publicize her early works at the Academy of Sciences in Paris through Pierre Curie. Pierre was not a member of the Academy, but he convinced his former professor and advisor to Marie Curie, scientist Gabriel Lippman, to read his wife's April 1898 results on Becquerel rays and spontaneous radiation release by uranium and thorium at the Paris Academy of Sciences. In July of the same year, the scientist Henri Becquerel presented at the Academy a communication discussing the Curies' results (Pugliese, 2012).

In addition to communications between scientists, the Academies of Science held awards. For example, the Paris Academy of Sciences awarded Marie its first Gegner prize in 1898, and 12 years later, she was awarded the Berthelot Medal (Pasachoff, 1996). Nevertheless, it was not until 1905, after Pierre's death, that she became head of the laboratory at the Sorbonne and had her first opportunity to earn a salary. These data point to the long time spent in research without remuneration, a characteristic of scientific work.

In summary, Marie Curie joined a prestigious academic space, and the established relationships in that environment allowed her production to circulate and, therefore, be recognized. Other factors were also fundamental to Curie's success, such as choosing the topic for her doctorate, which will be discussed in the next section.

Experimentation with radioactivity

Marie Curie had a long, non-linear, and complex experimental path to her device that established radioactivity as a general phenomenon. Such a device was not a laboratory instrument but a set of practices, techniques, and other activities used to detect radioactivity (Pugliese, 2012). In this way, some research and controversies accompanied the emergence of the doctoral theme in her life and building her experimental device.

Experimentation on radioactivity does not have a specific beginning (Cordeiro & Peduzzi, 2010). However, the German scientist Wilhelm Conrad Röntgen (1845-1923), who detected a hitherto unknown phenomenon in experiments, which he named X-Rays, popularized the study. Germany was part of the scientific, geographic center in the 19th century, and this centrality allowed the enigmatic X-Rays to leave the small laboratory in Würzburg, Germany, and reach large laboratories in other parts of Europe. Pugliese (2012) points out that "in less than a year, more than a thousand scientific communications were published on the subject, and X-rays became the major topic of research in Physics" (p.34). This is how the topic of X-rays circulated from Germany to France, arousing the interest of other researchers, among them Henri Becquerel (1852-1908), Marie Curie, and Pierre Curie.

The search for the relationship between phosphorescence and X-rays guided a good part of these scientific studies, including those by Frenchman Henri Becquerel, a Paris Academy of Sciences member. One of Becquerel's paths was experimenting with other substances exposing photographic plates (Martins, 1998a). At first, Becquerel (1896b) argued that the salts in ores absorbed solar radiation and, therefore, left them exposed to the sun. However, the only salt that caused the phenomenon of the image on the photographic plate was precisely the one that he had not left exposed to the sun. He concluded that this was a uranium-rich ore that emitted radiation different from solar radiation (Pugliese, 2012). When Becquerel observed that photographic plates were exposed to uranium salts even without sunlight, these hyperphosphorescent uranium rays became known as Becquerel rays, which were different from X-rays.

Becquerel reported his experiments in the scientific journal of the Paris Academy of Sciences in March 1896 (1896b). After releasing Becquerel's first experiments, other scientists researched uranium salts and published their work. Still, in March 1896, new research emerged around the experiments on Becquerel rays at the Academy of Sciences in Paris (Pugliese, 2012).

Marie Curie, giving up on returning to Poland, began researching her doctorate with Becquerel rays in the Sorbonne laboratories (Pugliese, 2012). In Europe, research on uranium radiation proved to be very fruitful, bringing new questions to the science of the early 20th century. Finally, however, the phenomenon gained a new interpretation in the hands of Marie Curie, accompanied by Pierre Curie (Cordeiro & Peduzzi, 2010). Until then, scientist Henri Becquerel frequently published the results of his research on the subject but always emphasized phosphorescence. Indeed, Marie and Pierre arrived at a result that opened up new possibilities for studying the problem: radioactivity as a general phenomenon.

Cordeiro and Peduzzi (2010) emphasize that Marie and Pierre Curie's significant contribution to uranium and thorium radiation research would have been detection through electrical methods. Their method measured the electricity generated by the radiation of the elements, which reduced the number of errors compared to the commonly used photographic method. Electromagnetism was one of the areas in which Pierre and his brother worked, for which they invented a highly accurate device, the piezoelectric quartz electrometer, an instrument that was part of Marie Curie's experimental device. This electrometer proved capable of measuring the electricity generated by uranium rays (Pugliese, 2012). Pierre Curie's partnership was essential for the scientist to obtain a laboratory composed of an ionization chamber, a piezoelectric quartz electrometer, and pitchblende ore, instruments that proved to be fundamental for the success of her research.

Marie Curie's doctoral research initially aimed to compare Bequerel rays with X-rays (Pugliese, 2012). However, her investigation began to take on more significant proportions when the uranium rays turned out to be different from those known until then because nothing seemed to affect them. Using the piezoelectric quartz electrometer, Marie Curie concluded that the rays emitted by uranium salts were constant and indifferent to any relationship with the environment. The scientist then checked if other ores produced the same effects and tested the ores available at the that contained metals such as copper, zinc, lead, tin, platinum, iron, gold, palladium, cadmium, antimony, molybdenum, tungsten, and thorium (Pugliese, 2012). She observed that most of those ores did not set off the piezoelectric quartz electrometer but that this phenomenon was not unique to uranium because chemical compounds of thorium emitted rays similar to those of uranium. This result indicated that there could be a more general phenomenon than something specific to uranium (Pugliese, 2012).

Next, Marie Curie decided to measure the radii of pitchblende and chalcocite in a piezoelectric quartz electrometer. Unexpectedly, they emitted more intense rays than the amount of uranium and thorium could initially emit. Previously, Becquerel had already noticed that metallic uranium produced more intense rays than any of its compounds, which led him to name this phenomenon hyperphosphorescence. Now, Marie Curie was faced with a result in which pitchblende emitted rays more intense than the uranium metal alone.

With help of Pierre, Marie Curie carried out experiments on the separation of the active substance (uranium) in pitchblende. After the separation, she noticed that pitchblende was still more active when activating the piezoelectric quartz electrometer than isolated uranium. She considered the results fundamental and intended to make them public. Gabriel Lippman read his results at the Academy of Sciences in Paris in April 1898. In his communication, Curie (1898) related the spontaneous radiation of uranium to its great atomic weight; that is, his initial hypothesis was that radioactivity was an atomic phenomenon.

In the same communication, Curie (1898) also suggested a new element in pitchblende. Once again, the scientist used analytical separation methods, finding the first active substance that she named "polonium." However, pitchblende still emitted more active rays than the supposed new element, suggesting that "polonium" might be more than one element, which prompted the couple to perform more experimental, analytical chemistry procedures to test the separate substances (Pugliese, 2012). The experiments led them to a second radioactive element besides polonium, which Marie named radium.

For four consecutive years, the scientist worked in the laboratory for radioactivity with the help of Pierre. In 1898, Marie and Pierre Curie presented the chemical elements – radium and polonium – that support radioactivity as a general phenomenon (Quinn, 1997). According to Pugliese (2012), the hyper-phosphorescence of uranium rays was brought into controversy through the experimental device created by Marie Curie, which led radioactivity to be considered a general phenomenon.

In the 1911 Nobel Prize in Chemistry speech, Marie Curie (1911) explains how her experimental practices led her to understand that pitchblende and chalcocite ores were much more active than anticipated due to the amount of pure uranium and thorium they contained. However, the idea of a new chemical element, along with the general phenomenon, was greeted with disdain at the time by members of the Academy of Sciences (Quinn, 1997). There was not even work in the sections of the Academy after reading Marie's results that referred to her studies. Nevertheless, the initial reaction of the scientific community led Marie Curie to try to isolate that unknown substance to make it exist in their eyes (Pugliese, 2012). For this task, Marie Curie began work in analytical chemistry with the help of Pierre Curie and the assistant chemist of the , Gustave Bèmont (1857-1937).

Experimental practices in radioactivity had a long and complex path of laboratory research, funding, awards, speeches, and publication of results, a fundamental characteristic of experimentation, which can be analyzed from the Nobel Lectures by Pierre Curie (1905) and Marie Curie (1911).

The experiments to isolate the elements underwent complex back-and-forth sequences due to results that did not match the scientists' expectations. The Nobel Lecture given by Madame Curie (1911) indicates that the couple had access to the work of several scientists, such as those of Becquerel, Demarçay (with spectral analyses), Debierne (discovered actinium and helped Marie Curie to isolate metallic radium), Rutherford and Soddy (proposed the theory of the transmutation of the elements, based on the radioactive phenomena proposed by the couple). In addition, in the discussion on the activity of rays, Marie Curie argued that chemical elements of greater atomic weight absorbed "external energy" and re-emitted it in the form of radioactive energy (Curie, 1898). From 1913 onwards, investigations into the causes of radioactivity gained new contours with the establishment of the Bohr-Rutherford atomic model. According to Pugliese (2012), everyone who wanted to study radioactivity in that context would have to use Marie Curie's experimental device.

Many conditions were necessary for the success of this long experimental journey: material resources, availability of time, the fact that the couple were in a large research center and had access to foundational articles in the area, and those that resulted from them were necessary, in addition to the collaboration of other scientists. Apart from that, Marie Curie was successful because she could be in a public space and not be distracted by her job in the private sphere, which was impossible for most women in that context (Schiebinger, 2001; 1989; Saffioti, 2015). Concerning Marie Curie's visibility, it is also important to highlight that the scientist dedicated many years to science alongside the work of motherhood. Reading excerpts from her diary present in Montero (2019) allows us to understand that the scientist could reconcile both jobs thanks to the help of a nanny.

In the 1906 diary, written shortly after Pierre Curie's death, Marie recalls the family's last outing before Pierre's death. She tells about going to Saint-Rémy-lès-Chevreuse, a country house, where they spent a few days in spring and summer. On April 30, 1906, she wrote in her diary: "[...] at the top, we sent Irène and **Emma** to the farm, and proceeded to the right, you and I, with Ève, in search of the ponds with water lilies from which we found ourselves. we remembered" (Curie, 1906 cited in Montero, 2019, p. 194, emphasis added).

The name of Emma, the nanny of his daughters, appears in excerpts of the diary. It is known that Marie Curie relied on the help of other women nannies for her daughters, which expanded her possibilities for working outside the home. In these memoirs, the scientist mentioned Emma, who helped her care for the house and the couple's children several times. She writes, for example, that she went to the country house in Saint-Rémy-lès-Chevreuse with her daughters, where it would be easier to spend her days without a nanny.

Marie wanted Pierre Curie to stay in St. Rémy with her and the girls, but he insisted on returning to the laboratory. On April 30, 1906, Marie describes in her diary the moment when her husband left home:

> [...] I left for St. Rémy on the Friday before Easter, it was the 13th of April, I thought it would do Irène good and I thought that it would be easier there to take care of Ève without the **nanny**. [...] **Emma** came back and you criticize her for not keeping the house well enough (she had asked for a raise). You were leaving, you had, I was taking care of you, and you left taking care of the girls, low voice if I was going to the bathroom. I replied that I didn't know and asked you not to torment me. And just then you went away; the last sentence I addressed to you was not a sentence of love and tenderness. Then I just saw you dead again. (Curie, 1906 cited in Montero, 2019, p. 189, emphasis added)

The presence of a woman working as a nanny in the private sphere of the Curie family to enable Madame Curie to work in the public sphere is also a matter of class division, essential to understanding how patriarchy is maintained, suggested by Perrot (2006), Saffioti (2015) and Biroli (2018). According to Perrot (2006), women withdrew from public spaces and shifted into private female family spaces in France in the 19th century. This withdrawal was a gender issue that encompassed different classes, suffering the contradictions of both categories. Housewives were rural women, bourgeois women, and city women who devoted themselves almost exclusively to domestic work and depended on their husbands' wages. Class differences between women in the patriarchy are reflected in the relationship between Marie Curie, as a woman who works as a scientist in the public space in a renowned university, and Emma, a woman who works in the domestic space, as a nanny, at Marie's house.

Generally, experimental practices refer to the process of producing radioactivity. Indeed, these also involved funding to obtain locations and material to carry out scientific research, awards, and publication of results that allowed knowledge to be further investigated around the globe through the articulation between scientists and their ideas.

Regarding the Marie Curie case, she suffered many obstacles set up by the patriarchy in her trajectory as a scientist. In this sense, she needed the right conditions to confront these obstacles and remain in the area. The scientific practices that permeate the Marie Curie case can reflect the conditions necessary for women to do science in the patriarchy.

NECESSARY CONDITIONS FOR WOMEN IN SCIENCE BASED ON THE MARIE CURIE CASE

The research on the Marie Curie case was constructed from the historiographical perspective of the CHoS. As a result, this section will discuss questions that identify some of the conditions that allowed female scientists to participate in science and how these conditions reflect the motives behind low numbers of females in science and, thus, build support for the research objective.

Marie Curie's visibility – and the invisibility of other women in science – can be expressed in a series of facts. Curie was the first woman who graduated in science with a degree in Physics, Chemistry, and Natural History (P.C.N) when in general, women studying in France studied the humanities. She was also the first professor to work in a laboratory at the Sorbonne, the first woman in science to be awarded a Nobel Prize, the first and only person to receive two Nobel Prizes in different categories until the year 2021, and the only woman to have a daughter who is also a Nobel laureate in the scientific field. The historic nature of this very recently relevant accomplishment highlights both her visibility and the invisibility of other diverse women in science.

Suggesting that a careful examination of the history of science would not reveal gender equity, El Jamal and Guerra (2020) posed a question: if scientific reasoning is a competence that everyone can achieve, then why do women seem to be outside the HoS? Other women from the 19th and 20th centuries did not become visible in the HoS, not for lack of effort or merit, but because the conditions were not there. The absence of scientific events involving women indicates that many of them were left out of science due to the unfavorable conditions of the patriarchy and the insurmountable obstacles of gender, race, or class to doing science.

Unlike many women, Marie Curie entered the academic environment and succeeded, facing obstacles to participating in scientific practices. However, minimal and favorable conditions were necessary to overcome some of these obstacles. Therefore, she should not be seen as privileged but as a woman who managed to do science – which many women still could not do – because the conditions were right. Therefore, this case suggests that these conditions must be expanded to reverse the low numbers of women in science.

On the one hand, there were obstacles placed by the patriarchy along her trajectory. On the other hand, some conditions allowed her to overcome these obstacles to a degree. The first obstacle was the institutionalization of female education, clandestine in Poland and incipient in France. Among favorable conditions, she had the opportunity to migrate to a scientific production center and remain there, in the French capital, despite the high housing costs (Perrot, 2006; Picard, 2010; Weisz, 1983). A second obstacle was the gender inequality among peers in the scientific environment, specifically not being allowed to publish in the Academy of Science. She overcame this obstacle by marrying a scientist, obtaining French nationality, and achieving a family-academic balance for herself and her daughter Irène Curie (Pugliese, 2012). Marie Curie was in France, a global center for the proliferation of scientific knowledge, alongside Pierre Curie, and researching a topic of interest to the scientific community, making successful relationships. A third obstacle was reproduction: the need and the difficulty of reconciling the jobs of scientist and mother, given the insalubrity of her first laboratory. However, Marie Curie was able to occupy the public spaces of scientific work with the help of nannies, which allowed her to spend time outside the work of reproduction. While she relied on nannies to help her take care of her daughters, possibilities for work outside the home expanded, and she dedicated herself for years to experiments on the separation of polonium and radium.

In addition to working somewhat outside the sexual division of labor, Curie had a family of professors who encouraged and supported her scientific career. According to Avraamidou (2019), most students who choose to do science come from families from more privileged socioeconomic classes and with more significant cultural capital, allowing broad access to science, knowledge, museums, and libraries. However, as in Marie Curie's context, science was aimed at the French elite of the 19th century, and the French higher education system was peripheral to the majority of the population (Weisz, 1983; Terrall, 1995; Picard, 2010).

Participating in scientific practices and staying in science requires favorable material conditions, like funding and time to dedicate to research (Schiebinger, 2001; Avraamidou, 2019). According to Saffioti (2015), the contradictions of patriarchy do not operate only in the category of gender, race, or class but in the loose connections between the three (Saffioti, 2015). In this sense, the visibility of people in science seems to be related to the contradictions of social class, race, and gender. Analyzing these contradictions helps contextualize the obstacles that Curie had to face to become visible and understand that the other women in science lack visibility because they lack these same conditions necessary to overcome these obstacles.

Unlike Marie Curie, other women in the history of science participated in scientific work within their domestic spaces and did not have the opportunity to engage in academic circles and dedicate themselves to science. Opitz (2016), for example, reports on the German Agnes Pockels (1862-1935). She experimented with surface films in the 1900s in her kitchen while carrying out household responsibilities related to care for the elderly and, therefore, Agnes did not have a trajectory that would make her visible. Other examples suggested by Schiebinger (2001) are the case of Margaret Huggins (wife of British astronomer William Huggins), Edith Clements (wife of ecologist Frederic Clements), and Mileva Maric (wife of Albert Einstein). They silently contributed to their husbands' careers without finding a space for action in the public spheres.

Greater visibility in the academic and scientific space comes from access to a prestigious university, which guarantees fruitful institutional relationships and conditions for experimentation. Moreover, these relationships could be maintained with Curie being a mother because, with the help of other women, she did not have to dedicate 100% of her time to reproduction/domestic work. Having help with housework and childcare allowed her to work outside the home for many years, becoming visible in the scientific field. However, this flexibility is not possible for all women who study science, even in the 21st century, indicating that this is an essential factor in understanding Curie's visibility and, at the same time, the invisibility of many other women in that and other contexts. Furthermore, women scientists must have the material conditions to dedicate themselves to their careers, referring to multi-year scholarships. This patriarchy-capitalism contradiction reduces the participation of women in science (Schiebinger, 2001; Saffioti, 2015).

Marie Curie's presence at the Faculty of Science in Paris and her experimental device demonstrated immense importance and a milestone in women's history, especially in France (Pugliese, 2012). However, even after the Marie Curie case, few women are visible in science because success in science depends on various interdependent factors, including access to education and prestigious scientific institutions (Schiebinger, 2001). Furthermore, in capitalist and patriarchal societies, the division of labor between job and home, and the academic career clock versus the biological clock, have deep historical roots, being an obstacle to women's entry into scientific professions (Schiebinger, 2001).

These considerations about the conditions that made Marie Curie visible in the history of science and explained some of the difficulties of women in scientific careers must be introduced in science education that is intended to be more politicized, as proposed by Hodson (2010), Rudolph, and Horibe (2016), Hodson and Wong (2017), and El Jamal (2021). According to Hodson (2010), science education should encourage the critical rationality of subjects, forming "the basis for the type of social action that reforms society and its practices" (p.199). This analysis is presented here under the historiographical lens of the CHoS because studying scientific practices produces evidence of the central point: without the time and resources, including access to and permanence in knowledge centers, eventual migrations, and gender equality, it is impossible to do science. By understanding this, male and female students can be more critical and engage in sociopolitical actions to improve conditions for women in society.

As discussed in institutionalizing female education in France, the Franco-Prussian war was fundamental for the entry of international students into the country. However, feminist movements in France and worldwide played a crucial role in women entering universities (Perrot, 2006). Perrot (2006) states that the French feminist movement was late and notes late access of French women to the right to suffrage, compared to Anglo-Saxon countries. Despite this delay, it is clear that the feminist movement was evident in different struggles of women in France in the 19th and 20th centuries. Therefore, despite the entry of women into French higher education following the political contingencies of the Third Republic, female education was also closely related to the history and movement of women in the country.

According to Schiebinger (2001), women entered careers in science only after the women's movement of the 1870s and 1880s propelled them to universities. Moreover, as they were admitted to graduate schools, they entered doctoral programs, which in the 19th and 20th centuries was already a prerequisite for serious dedication to science. Unfortunately, the process of women entering university was beset with many difficulties.

Perrot (2006) suggests that the 19th century was marked by the sexual division of labor based on biological sex differences. The division between public and private changed over time and was strongly present in the 19th century, a liberal century characterized by the double exclusion of proletarians and women from political spaces (Perrot, 2006). In France, concomitant with the sexual division of labor was the increasing responsibility of women for the role of housewife. In this sense, Marie Curie conquered an unusual space for women.

Modern 19th century France was characterized by the confinement and guardianship of women[1]. However, despite this accentuation of patriarchy, a women's movement began in the country. The sharp division between the public and private spheres in this century and the unfavorable conditions of women served as motivation for the incipient birth of a feminist movement in the early 20th century.

At the end of the 19th century, French universities had an admission policy to attract young foreigners from economically underdeveloped countries. Like Marie Curie, immigrants faced high housing prices in crowded cities. Then, in 1848, Parisians demanded the suspension of housing payments, and women were a group that was present in opposition against the capital's high prices (Perrot, 2006). In the same year, women spoke out against religious congregations, priests, and convents, which, until then, were responsible for female education (Perrot, 2006). In general terms, despite the difficulties women face as a result of patriarchy, Perrot (1995) suggests that women have been the protagonists in changing the role of women, especially at the turn of the 19th to the 20th century. According to Perrot (1995), the desire to balance paid work (guaranteeing independence) and motherhood are present in 19th century France. In this same perspective, Schiebinger (2001) emphasizes that women's history in science and society was not one of the victorious advances, but of cycles of advance and retreat, accompanied by the political context and social movements, which are always necessary for social transformations in history and scientific practices.

LINKS BETWEEN NECESSARY CONDITIONS FOR WOMEN IN SCIENCE AND SCIENCE EDUCATION IN BRAZIL

The micro-history supported by the CHoS, presented here in this article, demonstrates particularities in science production and the necessary conditions to produce science. Despite being a case of a French woman, discussion about Madame Curie's working conditions can be introduced into science education in Brazil to improve understanding of the relationship between science and patriarchy in favor of sociopolitical action.

In Brazil, statistical data are provided by the 2019 Brazilian higher education census[2]. The Census reveals that of the 3.6 million students who enter higher education, 84.6% are in private institutions, 64% of the degree courses are in private institutions, and 72.2% of the students enrolled in the degrees are women. These results show that most of the Brazilian population who attend higher education are in private institutions and that degrees are predominantly sought by women.

Concerning women's work and education, according to gender statistics and social indicators identified by the Brazilian Institute of Geography and Statistics (IBGE)[3] in 2018, there is a minority in the country with complete higher education. They are 23.5% white women, 10.4% black or mixed-race women[4], 20.7% white men, and 7.0% black or mixed-race men. Furthermore, the time dedicated to caring for people or household chores is 18.1 hours per week for women, longer for black or mixed-race than for white women, and 10.5 hours per week for men in total. The average monthly income from all jobs for women is 1764 reais (about USD$355) and for men is 2306 reais (about USD$438). Bárbara Cobo, coordinator of Population and Social Indicators at , concludes that women are more educated than men, but this is still not reflected in the labor market because women choose occupations with a more flexible working day to reconcile work with the burden of household chores. On the condition of women in economic structures, participation in productive activities, and access to resources, Bárbara Cobo adds that inequalities in the labor market can only be resolved through an integrated daycare policy since one of the main factors for women to leave the formal school system or the job market is domestic work.

These data suggest that conditions do not favor women's participation in professions that require extensive training time, total dedication, and material resources, such as work in the scientific field. This assertion agrees with Hodson (2010) when the author points to teaching and learning that prepare young people for sociopolitical actions. Therefore, education strategies that question the low representation of women in science need to promote understanding of the historical conditions of female participation in science, arguing that such conditions can be changed.

Therefore, science teaching needs to follow a more politicized approach, whereby students can establish relationships between the exploitation/domination of vulnerable groups and science, realizing the position in the world they occupy. According to Hodson (2010), there is no motivation for sociopolitical action without critical awareness of their world positions. Motivation for sociopolitical action also comes from knowing how and why others made sociopolitical changes with personal goals in mind for building a world and community (Hodson, 2010).

The historical example of Marie Curie under the historiographical lens of the CHoS shows that to be part of the scientific enterprise, women need favorable conditions. As these conditions are denied to most women, social movements are fundamental in demanding, for example, broad access to education, remuneration for female reproductive work, or policies that release women from responsibility for such work. In France, for example, it was only a decade later that French women provoked changes in laws that gave men sexual rights over women, as in the Napoleonic Penal Code (Saffioti, 2015). Likewise, the struggle for better conditions for women in Brazil depends on the movement of Brazilian women themselves.

> History reveals that the great causes, especially beneficial to the discriminated contingents and almost everyone else, were successful, despite being led by small minorities. And Brazilian women have plenty of reasons to oppose the machismo present in all social institutions (Saffioti, 2015, p.49)

Approaching the Marie Curie case through the CHoS is a pathway to politicized science education. However, discussing the necessary conditions for women in science can motivate Brazilian students to collective sociopolitical actions, such as anti-patriarchal social movements.

FINAL CONSIDERATIONS

The present research sought to explore conditions that allowed Marie Curie to participate in science and how understanding these conditions creates opportunities in education for critical discussion about low female participation in science.

The discussions presented are based on the difficulties of using patriarchy to justify low women's representation in the history of science. Among the difficulties are the consolidation of a predominant sexist epistemology in science, gender inequality, the assumed social roles for women, female responsibility for domestic and reproductive work, lack of access to education, and lack of material resources for staying in science (Federici, 2019; Harding, 2015; Saffioti, 2015; Schiebinger, 2001; 1989).

Highlighting Marie Curie's success in the literature agrees with the work of Brickhouse (2000; 1994) and Carlone et al. (2015), who advocate recognizing students with scientific identities to inspire more women to do science. However, the present results suggest that just introducing examples of women in the history of science is insufficient to increase female representation. The Marie Curie case demonstrates that visibility in the area depends on favorable conditions to participate in scientific practices and, therefore, to have more women in science, these structural conditions must be improved.

The disproportionality between men and women in HoS questions the absence of a vast majority of women in science without turning an individual case into a triumphant example. According to Schiebinger (2001; 1989), works that only mention notable figures do not question the difficulties that prevent most women from entering scientific professions. Therefore, a critical education strategy would presuppose an understanding of power relationships in the process of science construction. This understanding facilitates discussions about how the structure of scientific institutions and patriarchy needs to change so that more women can enter and remain in scientific careers (Schiebinger, 2001).

The present research adds depth to the case of a woman in science, recurrent in the literature, with questions about patriarchy. Discussions in science classes about low female participation in science careers would improve understanding of science, confront persistent patriarchal attitudes, and promote sociopolitical actions in an education strategy guided by contemporary political issues for social transformations.

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REFERENCES

Avraamidou, L. (2019) “I am a young immigrant woman doing physics and on top of that I am Muslim”: Identities, intersections, and negotiations. *Journal of Research in Science Teaching*, 57(3), 1-31. https://doi.org/10.1002/tea.21593

Becquerel, H. (1896). Emission de radiations nouvelles par l’uranium metallique. *Comptes Rendus de l’Académie des Sciences*. Paris, 122, 1086-1088.

Biroli, F. (2018) *Gênero e desigualdades:* Limites da democracia no Brasil. São Paulo: Boitempo.

Brickhouse, N., Lowery, P., & Schultz, K. (2000). What Kind of a Girl Does Science? The Construction of School Science Identities. *Journal of Research in Science Teaching*, 37(5), 441–458. https://doi.org/10.1002/(SICI)1098-2736(200005)37:5<441::AID-TEA4>3.0.CO;2-3

Brickhouse, N. (1994). Bringing in the outsiders: reshaping the sciences of the future. *Journal Curriculum Studies*, 26(4), 401-416. https://doi.org/10.1080/0022027940260404

Burke, P. (2008) *O que é história cultural?*. Rio de Janeiro: Zahar.

Carlone, H. B., Johnson, A., & Scott, C. (2015). Agency amidst formidable structures: How girls perform gender in science class. *Journal of Research in Science Teaching*, 52, 474-488. https://doi.org/10.1002/tea.21224

Cordeiro, M. D. (2020). Reflexões da história do patriarcado para esses tempos de pós-verdade. *Caderno Brasileiro de Ensino de Física*, 37(3), 1374-1403. https://doi.org/10.5007/2175-7941.2020v37n3p1374

Cordeiro, M. D., & Peduzzi, L. (2010). As conferências Nobel de Marie e Pierre Curie: a gênese da radioatividade no ensino. *Caderno Brasileiro de Ensino de Física*, 27(3), 473-514. https://doi.org/10.5007/2175-7941.2010v27n3p473

Curie, M. (1898) Rayons émis par les composés de l’uranium et du thorium. *Comptes Rendus de l’Académie des Sciences*. Paris, 126.

Curie, M. Diários de Marie Curie (1906). Apêndice. In: Montero, R. *A ridícula ideia de nunca mais te ver* (pp. 189-205). São Paulo: Todavia.

Curie, M. (1911). *Marie Curie - Nobel Lecture 1911*. Disponível em <https://www.nobelprize.org/prizes/chemistry/1911/marie-curie/lecture/>. Acesso em: 9 ago. 2020.

Curie, P. (1905). *Pierre Curie - Nobel Lecture 1905***.** Disponível em <https://www.nobelprize.org/prizes/physics/1903/pierre-curie/lecture/>. Acesso em: 04 nov. 2020.

El Jamal, N. (2021). *O Lado Invisível da História da Ciência*: Discutindo a ausência de mulheres na Ciência por meio da visibilidade de Marie Curie na Educação em Ciências. (Dissertação Mestrado). Diretoria de Pesquisa e Pós-Graduação em Ciência, Tecnologia e Educação, Centro Federal de Educação Tecnológica Celso Suckow da Fonseca, Rio de Janeiro.

El Jamal, N., & Guerra, A. (2020). O lado invisível na história da ciência: uma revisão bibliográfica sob perspectivas feministas para a educação em ciências. *Revista Debates em Ensino de Química*, 6(2), 311-333.

Federici, S. (2019) *Mulheres e caça às bruxas:* da Idade Média aos dias atuais. São Paulo: Boitempo.

Fyfe, A. Journals and Periodicals (2016). In: Lightman, B. (ed.), *A Companion to the History of Science* (pp. 387-400). Oxford: Wiley Blackwell.

Gooding, D. Putting Agency Back into Experiment (1992). In: Pickering, A. (ed.), *Science as a Practice and Culture* (pp. 65-113). Chicago: The University of Chicago Press.

Harding, S. (2015). *Objectivity and Diversity: Another Logic of Scientific Research.* Chicago: The University of Chicago Press.

Hodson, D. (2010). Science education as a call to action. *Canadian Journal of Science, Mathematics and Technology Education*, 10(3), 197-206. https://doi.org/10.1080/14926156.2010.504478

Hodson, D., & Wong, S. L. (2017). Going beyond the consensus view: Broadening and enriching the scope of NOS-oriented curricula. *Canadian Journal of Science, Mathematics and Technology Education*, 17(1), 3-17. https://doi.org/10.1080/14926156.2016.1271919

Keller, E. F. (1985). *Reflections on gender and science.* New Heaven: Yale University Press.

Kirby, D. A. Film, Radio, and Television (2016). In: Lightman, B. (ed.), *A Companion to the History of Science* (pp.428-443). Oxford: Wiley Blackwell.

Livingstone, D. (2003). *Putting Science in its Place, Geographies of Scientific Knowledge*. Chicago: The University of Chicago Press, 2003.

Luz, C. (2004). Como o Código Civil Francês se adaptou ao longo do tempo. *Revista da EMERJ*, 7(26), 24-35.

Martins, R. (1998a). A descoberta dos Raios X: O primeiro comunicado de Röntgen. *Revista Brasileira de Ensino de Física,* 20(4), 373-390.

Martins, R. (1998b). A descoberta da radioatividade. In: SANTOS, Carlos Alberto. *Da Revolução Científica à Revolução Tecnológica* (pp.29-49). Porto Alegre: Instituto de Física da UFRGS.

Mayeur, F. (2007). Les territoires d'une historienne. *Histoire de l'éducation* (online), 115-116. https://doi.org/10.4000/histoire-education.1418

Moulinier, P. (2002). La Naissance de l'étudiant moderne (XIXe siècle). *Histoire de l'éducation* (online), 110-113. https://doi.org/10.4000/histoire-education.492

Moura, C. B., & Guerra, A. (2016). História Cultural da Ciência: Um Caminho Possível para a Discussão sobre as Práticas Científicas no Ensino de Ciências? *Revista Brasileira de Pesquisa em Educação em Ciências*, 16(3), 725-748.

Nyhart, L. K. Historiography of the History of Science. (2016). In: Lightman, B. (ed.), *A Companion to the History of Science* (pp.7-22). Oxford: Wiley Blackwell.

Opitz, D. L. Domestic Space (2016). In: Lightman, B. (ed.), *A Companion to the History of Science* (pp.252-267). Oxford: Wiley Blackwell.

Owens, T. (2009). Going to school with Madame Curie and Mr. Einstein: gender roles in children's science biographies. *Cultural Studies of Science Education*, 4(4), 929-943. https://doi.org/10.1007/s11422-009-9177-6

Pasachoff, N. (1996). *Marie Curie and the Science of Radioactivity.* Oxford: Oxford University Press.

Perrot, M. (1995) Escrever Uma História Das Mulheres: relato de uma experiência. *Cadernos Pagu*, (4), 9-28.

Perrot, M. (2006). *Os Excluídos da História:* Operários, Mulheres, Prisioneiros. São Paulo: Paz e Terra.

Picard, E. (2010) A história do ensino superior francês: por uma abordagem global. *Revista Educação,* 33(2), 145-155.

Pimentel, J. (2010). ¿Qué es la historia cultural de la ciencia? *Arbor Ciência, Pensamento y Cultura,* 186(743), 417-424. https://doi.org/10.3989/arbor.2010.743n1206

Pugliese, G. (2012). *Sobre o "Caso Marie Curie"*: a Radioatividade e a Subversão do gênero. Santa Catarina: Alameda.

Quinn, S. (1997). *Marie Curie*: uma vida. São Paulo: Scipione.

Rudolph, J. L., & Horibe, S. (2016) What do we mean by science education for civic engagement? *Journal of Research on Science Teaching*, 53(6), 805-820. https://doi.org/10.1002/tea.21303

Saffioti, H. (2015). *Gênero, Patriarcado, Violência.* São Paulo: Expressão Popular.

Schiebinger, L. (2001). *O Feminismo Mudou a Ciência?* Bauru: Editora da Universidade Sagrado Coração.

Schiebinger, L. (1989). *The Mind Has no Sex? Women in the Origins of Modern Science.* Harvard University Press.

Sigrist, N. T. (2009). Mulheres e a Universidade na França, 1860-1914. *Histoire de l'éducation* (online), 53-70.

Terrall, M. (1995) Gendered Spaces, Gendered Audiences: Inside and Outside the Paris Academy of Sciences. *Johns Hopkins University Press*, 3(2), 207-232.

Weisz, G. (1983). *The Emergence of Modern Universities in France: 1863-1914.* New Jersey: Princeton University Press.

NOTES

1 Article 213 of the French Civil Code of 1804, in effect at the time of Marie Curie, treated women as the husband's property and guardianship by nature, the Civil Code establishes absolute authority for the husband. The married woman ceases to be a responsible individual. Dedicated to marriage, the law asserted man's superiority, stating that the husband should protect his wife and the wife owes obedience to her husband. The wife could not have another domicile, she could not take legal action without her husband's authorization, nor could she buy or sell without his approval (LUZ, 2004).

2 INEP. (2019). Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira. Censo da Educação Superior. Brasília: MEC.

3 IBGE. (2018). Instituto Brasileiro de Geografia e Estatística. Estatísticas de Gênero: Indicadores sociais das mulheres no Brasil. *Estudos e Pesquisas – Informação Demográfica e Socioeconômica*, (38), 1-13.

4 A caracterização "preto" e "pardo" é dada pelo IBGE.

Natasha Obeid El Jamal
Mestre em Ciência, Tecnologia e Educação com ênfase em História da Ciência e Ensino pelo Centro Federal de Educação Tecnológica Celso Suckow da Fonseca (CEFET), Rio de Janeiro, RJ, Brasil. Núcleo de Investigação em Ensino, História da Ciência e Cultura do CEFET/RJ.
E-mail: natashaobeideljamal@gmail.com

Andreia Guerra
Doutora em Engenharia de Produção com ênfase em História da Ciência (COPPE/UFRJ).
Professora do Centro Federal de Educação Tecnológica Celso Suckow da Fonseca (CEFET), Rio de Janeiro, RJ, Brasil. Núcleo de Investigação em Ensino, História da Ciência e Cultura do CEFET/RJ.
E-mail: andreia.moraes@cefet-rj.br

Contato:
Programa de Pós-Graduação em Ciência, Tecnologia e Educação – PPCTE
Centro Federal de Educação Tecnológica Celso Suckow da Fonseca (CEFET),
Rua General Canabarro, 485 - Maracanã,
Rio de Janeiro – RJ I Brasil
CEP 20.271-204

Editor responsável:
Luciana Sá

Contato:
Centro de Ensino de Ciências e Matemática de Minas Gerais – CECIMIG
Faculdade de Educação – Universidade Federal de Minas Gerais
revistaepec@gmail.com