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Essay

Revisiting Male Allies in Mathematics and Physics Throughout History: Role Models for Men in STEM Education

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Abstract: In the academic world, there are also gender inequalities, which are especially visible in certain masculinized STEM areas, such as physics and mathematics. An essential factor in correcting these inequalities is the involvement of men, who should act as "allies" in the university setting. Likewise, as the literature shows us, we must offer models with gender-incongruent roles to break down stereotypes and promote non-traditional behaviors. However, to date, these actions have been especially directed toward women, who generally do not hold power and therefore have less possibility of promoting change. For the first time, this work compiles, in a single document, important male physicists and mathematicians who acted as allies of women throughout history. These examples can be presented to provide male references in the teaching of physics and mathematics at university (and high school). With this initiative, we intend to contribute to incorporating the gender perspective in university teaching, since, in practice, university professors are unaware of references of alternative masculinities in the academic world. We hope that this article will be the seed to recover hidden male allies in these and other scientific fields. This can help break down stereotypes, and contrary to previous actions, this work is especially directed toward men.

Keywords: mathematics education; physics education; STEM teaching; mathematics history; physics history; gender equality; male advocates; masculinities; stereotypes

MSC: 97C60; 01A70; 97U99; 00A05; 00A79

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1. Introduction

Gender inequalities persist even in countries with high rates of gender equality. For example, in recent years, different laws have been approved in Spain that have made it one of the most advanced countries with respect to gender equality. In fact, according to a report from the European Institute for Gender Equality (EIGE), Spain is the fourth country in the European Union (EU) on the gender equality index for 2021 [1]. But despite these advances in equality policies, there is still a gender wage gap in Spain and low co-responsibility, and in recent months, a worrying uptick in gender violence has been observed [2].

These problems also affect institutions such as universities, which could be the engine of change in our society, but which can hardly be so if the glass ceiling [3] and the gender wage gap [4,5] persist and situations of sexual harassment and gender-based harassment occur [6]. Similarly, Moss-Racusin et al. [7] revealed that scientists are biased in hiring and encouraging men over women. Sugimoto and Larivière [8] also revealed a gap in citations favoring men-led papers in most countries, in terms of both first authorship and last authorship. This situation favors vertical segregation that still persists in universities and public research organizations. In Spain, the report *Científicas en cifras 2023* (Female scientists in figures 2023) [9] shows that in the early stages of research careers, women and men are equally represented, but female talent is progressively being lost, until we find that women are under-represented at the highest positions, only 25.6% [9]. This fact contributes to a 12.7% pay gap in universities [4]. In addition, the report cited above shows that women obtain less funding, e.g., "in 2020, grants for the implementation of scientific research and technological development to proposals generated by women were a total amount of EUR 254.9 million, compared to EUR 420.7 million awarded to proposals generated by men. The amount awarded to women represents 37.7% of the total amount, which is much lower than the percentage obtained by men (62.3%)" [9] (p. 91). Furthermore, Cabero and Epifanio [10] laid bare the gender gap in childcare with Spanish academic staff. There was a difference of 30 h per week, on average, between female and male academic staff for care during the period of parenting. Therefore, gender roles continue to be present with Spanish academic staff, and this confirms the need for real changes in our institutions.

Having a legislative framework that favors gender equality is a great advance, but it is not enough. For example, a recent review of the study plans and teaching guides of the Primary Education Degree highlights that "the Teaching Guides, for the most part, use language that encourages the invisibility of women, they lack coeducational competencies, content, objectives and resources and have an unequal distribution between women and men present in the bibliography" [11] (p. 255). Likewise, the report *Científicas en cifras 2023* (Female scientists in figures 2023) emphasizes that "the integration of sex/gender analysis in the content of teaching is one of the unresolved issues that has not been achieved in all universities, since only two thirds of public universities and half of private universities claim to have carried out actions aimed at promoting the incorporation of the gender dimension in classrooms in 2022" [9] (p. 117), and this inaction is also confirmed by the report *Las políticas de igualdad universitarias* (University equality policies) prepared by the Spanish Network of Equality Units of Gender for University Excellence [12] and Epifanio and Calvo-Iglesias [13], who analyzed the actions for gender equality in scientific–technical areas in Spanish universities.

To understand this low mainstreaming of the gender perspective, we must take into account that, in recent years, neoliberal measures have been adopted in the university context that have encouraged teachers to prioritize research over teaching, both to consolidate their careers and in order to gain access to a permanent position [14,15]. These measures have especially affected young women with childcare responsibilities, because caring for family members or students continues to be a woman's task [16]. Furthermore, the data from the *Científicas en Cifras* report confirm low male participation, around 25%, in training actions on gender equality in universities and public research organizations. This gender imbalance in participation in equality training courses is worrying for two reasons. On the one hand, men continue to hold power in these institutions and monopolize the most important positions [17]. On the other hand, there are highly masculinized areas such as engineering, especially those related to computer science [18], physics, or mathematics, where it is necessary to introduce the gender perspective to end gender biases that can affect the development of technological products, as we can see in the development of AI [19], or in the detection of diseases that cost money and even lives [20]. By "masculinized areas" we mean that they are masculinized in terms of their perception and in terms of their practitioners. As Gonsalves et al. [21] indicated, "the discipline of physics is not only dominated by men, but also is laden with masculine connotations on a symbolical level, and that this limited and limiting construction of physics has made it difficult for many women to find a place in the discipline". Let us also recall that a few years ago, Strumia, a male particle physicist, stated that "Physics was invented and built by men, it is not by invitation" [22].

Therefore, to ensure greater equality, we need to increase the participation of men who act as allies of feminism within the university. And it is necessary to know what drives them to abandon their privileges in order to attract more men to these alternative masculinities [23]. In this paper, we will show the importance of providing masculine references within the framework of new masculinities or non-hegemonic masculinities and how we could incorporate them in the teaching of subjects such as physics or mathematics.

To the best of our knowledge, this is the first work that compiles male allies throughout history in these fields.

1.1. Egalitarian or Alternative Masculinities

Interest in egalitarian or alternative masculinities has increased in recent years in Spain. And although research on this topic is still scarce [24], already, "It is beginning to be considered that, without a change in men, it will not be possible to achieve gender equality" [25] (p. 60). Thus, several postgraduate courses on masculinities and equality have been launched, such as the one at Universidad Miguel Hernández; conferences have been held; and training is beginning to be provided to teachers and students on this topic. In fact, the Universitat Autònoma de Barcelona has launched the Masculinity Workspace, with which it aims to provide a support service aimed at men who want to rethink their way of relating from a non-sexist perspective. These courses and these spaces are important since, as López Ramos and Cifre [23] (p. 292) pointed out, "the change towards egalitarian masculinities requires a reflective and practical effort for the men who perpetuate it. An effort that cannot be achieved without some type of impulse from the social environment".

The promotion of equality within the university environment is essential in masculinized disciplines such as physics, mathematics, and engineering to put an end to the sexist norms that still persist in these disciplines and that prevent women from advancing. The study by Dancy and Hodari [26] showed us how men in the field of physics who supported the discourse of equality in their usual practices maintained sexist norms that invalidated those discourses. And as Sugimoto and Larivière [8] (p. 1) pointed out, gender disparities in science are seen as a thing of the past. The same goes for other types of discrimination, such as racism [27].

Therefore, people who occupy positions of power in these disciplines should participate and get involved in actions that favor equality, starting with training, because today, we should all know what the scissor graph represents in the evolution of teaching and research staff. This graph shows the evolution of women and men in their academic careers. As the trajectory progresses, before obtaining a doctorate and up to becoming a research professor, the percentage of women decreases and that of men increases. At the beginning, there are slightly more women than men (except in physics, engineering, and computer science (PECS) areas), so the two lines cross. This is why it is called a scissor graph.

Unfortunately, this is not the case [28], and we must assume the consequences of doing nothing, since if we are not part of the solution, we are part of the problem. In fact, recently, in Spain, ruling 134/2021, of 24 February, issued by the contentious administrative Chamber of the Superior Court of Justice of the Valencian Community [29], recognizes that discrimination can occur through omission, that is, by not acting when there is discrimination.

In recent years, equality measures in scientific and technical fields have focused mainly on women and girls and, more recently, on LGTBIQ+ people, forgetting that it is the groups with privilege that can favor change. Without abandoning these equality measures, we need other measures that allow us to incorporate more men because, as bell hooks [30] (p. XVII) stated "It is not true that men are unwilling to change. It is true that many men are afraid to change" .

And for this, it is necessary to facilitate the knowledge and visibility of alternative and egalitarian models of men. These models are not new, and as Bacete [31] (p. 30) highlighted, "dissidence, also in the male sphere, has always been present, although its different expressions have reached our days with difficulty, because the narrative of the stories of dissident men, as with that of women, it is also biased, conditioned and impacted by sexism". And throughout history there have been

> men such as Nicolas de Condorcet, Charles Fourier, William Thompson, John Stuart Mill, Léon Richer, Jin Tianhe and Tahar Haddad have supported the emancipation of women. They defended women's physical integrity, liberty of movement, and intellectual, civil and political equality. They demanded that women have the right to learn, work, vote, love and be autonomous. [32] (p. X)

In scientific and technical fields, we can also find examples of dissident men who have supported their female colleagues or disciples at work and in life. And we need to integrate them into our explanations and offer them as models to follow, as we will show in the next section.

1.2. Fair Men, Also in Science?

The vision of science and technology that continues to be transmitted in the classrooms is positivist. In general, the disastrous consequences that certain discoveries have had, such as those that led to the atomic bomb, or the consequences for humanity of this industrial capitalism that depletes natural resources and endangers our survival on the planet, are not analyzed. The fact that women were erased from the history of science and the scant recognition of their contributions is not questioned either. It continues to be thought that science is neutral and objective, forgetting that it is made by people and can therefore be affected in any way by their biases. Even though textbooks continue to transmit to us an androcentric vision of scientific knowledge, progress has been made, as reflected by the large number of books about female scientists aimed at children and young people.

In the narrative that continues to be shared about science, scientists continue to be presented as heroes or heroines, and their contributions are rarely questioned. Not only this, but we have recently seen how the premiere of the film *Oppenheimer* was celebrated. However, the event it depicts should be seen as the biggest failure in the history of science and technology due to the destruction that it caused. Furthermore, it should lead us to analyze the alliance between science and technology, and engineering and war throughout history. And the film ignores the role of Lise Meitner, whom the North American press labeled the mother of the nuclear bomb, in the discovery of nuclear fission [33]. In these times of energy and climate crises, surrounded by wars, we need other types of stories, where ethics and human values, like those shown by Lise Meitner who refused to participate in the Manhattan project, help us build a fairer world. This also concerns the vision of science that we teach in the classroom, where we must recognize not only scientific achievements but also the value they have had for society, including support for women in the field of science. In addition, it is necessary to change the approach to knowledge and methodology of Western science oriented toward the dominance of nature [34]. We need to do away with the masculinist approach that focuses on the use of technology to overcome this crisis and incorporate female and excluded voices, as well as social and gender justice concerns about the impact of climate change on women and vulnerable populations [34].

The history of science could be used as a teaching resource in this sense "since it allows us to extract from it the most significant problems that research had to face at the time, in addition to offering a sample of the controversial nature of scientific research, which is the result of the work of numerous people, mostly men, and ignoring the contributions of women scientists" [35] (p. 22). Thus, reinserting women into scientific history and reclaiming their knowledge and that of other traditionally excluded groups will contribute to ending the sexism, androcentrism, and colonialism that still permeate scientific knowledge. We would like to emphasize that we find it very interesting to use historical enrichment as a proposal to decolonize the curriculum [36]. But our proposal is focused on characters of the XIX and XX centuries that built the physics and mathematics that we mainly teach in university courses on physics and mathematics.

Since Enheduanna (2300 BCE), who is considered the first female author and also the first female scientist in history, there have been many women who have contributed to the advancement of science, mostly women from the upper classes or belonging to families of scientists, as is the case of many astronomers. As Sugimoto and Larivière [8] (p. 17) said,

> Before the twentieth century, science was associated with amateurism, which allowed wealthy women and those who married scientists to participate in scientific activities. Beginning in the 1870s, women increased their membership in scientific organizations and began obtaining employment in museums and observatories. By the end of the nineteenth century, however, science began a process of

professionalization that served to decrease women's access to scholarship. When science became codified as a professional—and therefore masculine—domain, women were further isolated from participation.

Until recently, we did not know their names, but today, thanks to books such as Hypatia's Heritage by Alic [37], which has inspired many others, we are already recovering them. And in addition to recovering their names and their legacy, we should also recognize the men who supported them, such as Pythagoras (490 BCE), known as "the philosopher friend of women", and Gösta Mitttag-Leffler (1846–1927), a defender of women's access to academic positions that they were prohibited from holding. We need role models of men who do not appropriate the discoveries of their female colleagues and who recognize their worth, as Pierre Curie did when he claimed the Nobel Prize for Marie Curie, as well as men who help and recognize female talent, such as William Herschel and Friedrich Pockels, who helped their sisters Caroline Herschel (1750–1848) and Agnes Pockels (1862–1935) develop their scientific talent. Although it is true that in the case of W. Herschel and others, his support could be interpreted as having been provided for his own benefit, as Donald [38] (p. 21) remarked, "Caroline Herschel was able to be an outlier, formidable although her contributions were, by virtue of the circles which she was able to penetrate through her brother". Similarly, we want male professors who value the abilities of their female students, such as Karl Weierstraß (1815–1897) and Max Planck (1858–1947) with Sofia Kovalévskaya (1850–1891) and Lise Meitner (1878–1968), respectively, although neither of them were, in principle, favorable to the admission of women to universities, and George Gamow (194–1968), who made it possible for Vera Rubin (1928–2016) to carry out her thesis. Moreover, it is important that, in our presentations, our virtual classrooms, and our teachings, when making these women scientists visible, we highlight the value of the male allies who helped them develop their talent. Because it is not fair that women, "as Gloria Steinem would say, (. . .) from the moment we enter kindergarten until we finish the doctorate, (. . .) we dedicate ourselves tirelessly to studying our own absence" [39] (p. 19), or that men do not have equal mirrors in which to look at themselves. We agree with Gonsalves et al. [40] on the utility of story-based methodologies for exploring the different paths followed to stay and belong in physics.

In secondary school, it is important to offer other stories about science [41] that can attract more women or minorized groups [42] to this discipline who do not identify with this supermasculinity that seems to dominate physics and other STEM areas.

2. Male Allies in Mathematics and Physics

A narrative review is considered. Unlike systematic reviews that are guided by procedures such as PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), there are no established procedures for narrative reviews. We follow the guidelines for narrative reviews suggested by Sukhera [43], which are as follows: (1) rationale for a narrative review; (2) clarity of boundaries, scope, and definitions; (3) justification for inclusion and exclusion criteria; (4) reflexivity and a saturation/sufficiency statement; and (5) details on analysis and interpretation. Regarding the first point, we chose a narrative review because this topic is under-researched, which is a situation where a narrative review is useful for educators [43]. We compiled evidence from multiple sources into one accessible and usable document. Some of those sources are "neutral", i.e., they limit themselves to stating certain facts. However, we considered a gender egalitarianism point of view (point 5). Therefore, this is also a critical review from the gender equality perspective. As regards point (4), narrative reviews do not aim to be inclusive of all literature about the topic. Therefore, for the sake of brevity, we prioritized including more scientists using a limited number of references per scientist than including many references for few scientists. Concerning points 2 and 3, they are specified as follows.

In this section, we will review male physicists and mathematicians who acted as allies of the female physics and mathematics (point 3) who usually appear in the syllabi of fundamental physics and mathematics subjects in Spain (point 2), not only in physics and mathematics degrees, but also in most science and engineering degrees; so, they would serve for STEM degrees in general. We will also point out the male mathematicians and physicists who not only were not allies but also actually acted against them in order to be especially careful and not use them as references (point 3). In addition to STEM degrees, mathematics, and especially statistics, is taught in degrees in the fields of health and social sciences. Consequently, the scope of application is not restricted only to STEM (point 2).

2.1. Mathematics and Statistics

Firstly, we will use some respected figures that appear in a basic statistics subject as a common thread, combining this with the introduction of respected figures in other areas of mathematics.

2.1.1. Descriptive Statistics

In the field of descriptive statistics, Florence Nightingale (1820–1910) [44] is a notable name as she was a pioneer in using statistical graphs to achieve changes in the strategies of authorities [45]. She had James Joseph Sylvester (1814–1897) as a tutor, known among other things for his contributions in the field of matrices. Sylvester was a friend of another illustrious mathematician, Arthur Cayley (1821–1895), who supported university education for women. In the early days of Girton College, Cambridge's first women's college, Cayley assisted in teaching. Additionally, he was chairman of the council of Newnham College, Cambridge's second women's college. Charlotte Angas Scott's (1858–1931) [46] thesis was directed by Cayley, who recommended that she move to Bryn Mawr College (USA) so she could work there. In this way, Scott was able to supervise the doctorates of at least eight female mathematicians, many of whom studied with Felix Klein (1849–1925) at the University of Göttingen.

Among Florence Nightingale's allies, with whom she worked and corresponded extensively, are the statisticians William Farr (1807–1883) and Lambert Adolphe Quetelet (1796–1874), recognized as one of the fathers of modern statistics. Together with Francis Galton (1822–1911) (a statistician recognized for various contributions, such as standard deviation, coining the terms percentile and correlation), he collaborated to create a new Chair of Statistics at Oxford, without success. However, we must be cautious with both Galton and other famous statisticians such as Karl Pearson (1857–1936) and Ronald Fisher (1890–1962), who had deep ties to eugenics and racial and class prejudices, and not use them as references, i.e., not be considered exemplars to be emulated. Instead, their history can be shown to reflect on the role of statistics in the world [47], i.e., bringing these figures up in the classroom could be useful. This recommendation concerns not only these particular statisticians; we must be wary more broadly, and we advise not to be blindly supportive of a particular scientist.

Galton's behavior was also sexist. He created a "beauty map" of the women of Great Britain based on the secret observation of women from different regions, whom he rated on a scale as attractive, indifferent, or repulsive, indicating his opinions on a piece of paper in the shape of a cross. His cousin, Charles Darwin (1809–1882), defended the inferiority of women to men. The following is an extract from a letter he wrote to Lady Caroline Kennard (1827–1907), a leading figure in the feminist movement of the time:

> I certainly think that women though generally superior to men [in] moral qualities are inferior intellectually; and there seems to me to be a great difficulty from the laws of inheritance, (if I understand these laws correctly) in their becoming the intellectual equals of man. [48] (p. 14).

Not only did Darwin consider women inferior, but he also added that women should not aspire to a life outside the home, since that would be detrimental to the happiness of children and homes [48].

2.1.2. Probability

Continuing with the concepts that appear in basic statistics subjects, in the field of probability, Borelian algebra is shown, in honor of Emile Borel (1871–1956). Borel supported the work of his wife Marguerite Appell (1883–1969), known as Camille Marbo, a renowned French feminist writer, and they both founded the scientific and literary magazine *Revue du Mois*. In 1911, he and Marbo hosted Marie Curie (1867–1934) in their home when Curie, then a widow, was attacked for her affair with Paul Langevin (1872–1946) (details can be found in the physics section), despite pressure from the French government to not accept her. Borel and Langevin were active in the defense of human rights. Borel proposed a law to guarantee the representation of women in municipal councils [49]. His social commitment also led him to be a member of the French Resistance during World War II.

More than a hundred years earlier, another mathematician, Nicolas de Condorcet (1743–1794), had been very active in defending women's rights, being in favor of the female vote, which was not achieved in France until 1945.

In Borel's academic family, we find another ally, his thesis supervisor, the illustrious Jean Gaston Darboux (1842–1917), who was involved in founding the École normale supérieure de jeunes filles in 1880. However, his academic grandson, Laurent Schwartz (1915–2002), winner of a Field Medal in 1950, although politically active (he was a Trotskyist and anti-colonialist, signing the Manifesto of the 121 on the Algerian War, for which his right to teach was suspended from 1961 to 1963) [50], did not actively support his wife, mathematician Marie-Hélène Schwartz (1913–2013), daughter of mathematician Paul Lévy (1886–1971), with no mathematical exchanges found between the couple [51].

Lévy was supervised by Jacques Salomon Hadamard (1865–1963) and Vito Volterra (1860–1940). Volterra was another distinguished mathematician, actively engaged in anti-fascism. He was one of 12 professors out of 1250 who refused to take the obligatory oath of loyalty to the fascist government of Benito Mussolini in 1931. Consequently, he was expelled from his position at the university and from his membership of Italian scientific academies, living abroad for much of the next few years and only returning to Rome just before his death in 1940. Volterra was an ally. In 1906, he proposed the founding of the Società Italiana per il Progresso delle Scienze (SIPS), at whose inaugural congress he was elected president and whose innovative statutes made it possible for women scientists to join the society. Volterra supported his female disciples, helping them to pursue careers, in contrast to the thinking held by some men according to which women could not reach the high spheres of mathematics [52]. Volterra worked with the following female mathematicians: Cornelia Fabri (1869–1915), Elena Freda (1890–1978) and her sister Eleonora Freda, Giuditta Graziani (18??–?), Cesira Orlandi (1881–?), Pierina Quintili (~1880–?), Emma Sciolette (1886–?), and Gina Zanoni (~1890–?).

Continuing with probability, another relevant name is Pafnuty Chebyshev (1821–1894), who got the illustrious Sofia Kovalévskaya (1850–1891) to be named an honorary member of the Saint Petersburg Academy of Sciences [53]. However, among Kovalévskaya's allies, we also find renowned physicists and mathematicians from other areas of mathematics apart from probability, such as the famous physicist Gustav Kirchhoff (1824–1887), who allowed her to attend his classes. A special mention should be made of the famous mathematician, Karl Weierstraß (1815–1897), considered the father of modern analysis, who was her mentor. Since she was not allowed to attend classes, Weierstraß tutored her, giving her private lessons for free for four years. Weierstraß made use of one of his former students, the mathematician Lazarus Fuchs (1833–1902) at the University of Göttingen, and through him and with a great deal of effort, in 1874, he managed to have Kovalévskaya awarded a doctorate without an oral exam, based only on the work she submitted. Another of Kovalévskaya's great allies was Gösta Mittag-Leffler (1846–1927), who gave her a position as a professor at Stockholm University in 1883, although the first year was without any salary (her students paid her), and she was appointed professor for life in 1889.

2.1.3. Probability Distributions

In probability distributions, many names of illustrious mathematicians appear, some allies and others not, as will be explained, pivoting around the eminent mathematician Sophie Germain (1776–1831). Sophie Germain was a self-taught mathematician since she was not allowed to access formal training [54]. The École Polytechnique, founded in 1794, did not admit women until 1972, at the end of the 20th century. Therefore, Germain obtained the notes of the famous mathematician Joseph Louis Lagrange (1736–1813) through a family friend, Antoine-Auguste Le Blanc, and submitted her work under his name. When Lagrange, who admired her work, met her, he encouraged her to continue, inviting her to the mathematical gatherings that he organized [55]. Another notable mathematician and ally was Adrien-Marie Legendre (1752–1833), with whom Germain collaborated on an equal footing. Baptiste Joseph Fourier (1768–1830) was also an ally. After being elected Permanent Secretary of the Academy of Sciences, Fourier allowed her to attend sessions, being the first woman who was not the wife of an academic to do so. Among Germain's allies, Karl Friedrich Gauss (1777–1855) stands out: he profusely praised Germain's talent, pointing out the prejudices and obstacles she suffered for being a woman, but as Mackinnon (1990) highlighted, it is not just the text but also the mathematics included in the letters that indicate that Gauss dedicated time to her. Gauss's public commitment to Germain is also shown in the posthumous granting of the title of honorary doctor by the University of Göttingen in 1831 due to the pressure he had to exert, since Gauss's request had already been rejected in 1830.

Among those who should not be included as reference figures are Pierre Simon Laplace (1749–1827) and his protégé Siméon Denis Poisson (1781–1840). Laplace organized a competition on the mathematical theory of elastic surfaces, thinking that the prize could go to Poisson, whom he also included on the jury (in this case, there were not only no obstacles but also "gifts"). After three anonymous attempts by Germain and some unethical maneuvers by Poisson, the Extraordinary Prize for Mathematical Sciences of the Paris Academy of Sciences went to Germain. Poisson, who we remember was also on the jury, was presented with the prize with the equation previously introduced by Germain but using false mathematical simplifications. Poisson publicly ignored Germain and was also unwilling to discuss mathematics with her. Poisson's response to a letter from Germain, in which she asked for his opinion on a series of mathematical reasonings, consisted simply of sending her his report, which symbolizes his contempt for Germain.

2.1.4. Mathematicians from the University of Göttingen

The University of Göttingen has been mentioned previously. One of its professors, the distinguished mathematician Felix Klein (1849–1925), could be considered the archetype of an ally, as he was one of the main advocates for women being able to study mathematics. This role as an ally was transferred to many of his students, who became the first male mathematicians to supervise doctoral theses by female mathematicians at their respective universities [56]. At Göttingen, women were able to attend the classes of Klein and other recognized mathematicians, such as David Hilbert (1862–1943), Carl Runge (1856–1927), and Hermann Minkowski (1864–1909) [57]. Klein changed his usual class greeting from "Gentlemen!" to "Listeners!" to be more inclusive, and if he ever got confused, he would rectify it with a smile [58] (p. 192).

Let us review some of the actions carried out by Klein in favor of women in mathematics. In 1891, the Kurator of the University of Göttingen denied the request of two female mathematicians to attend Klein's classes. To get around this refusal, in 1893, at the request of Mary Frances Winston (1869–1959) through her teachers Heinrich Maschke (1853–1908) and Oskar Bolza (1857–1942), Klein avoided the Kurator and communicated on several occasions with the Prussian Minister of Education, who was more open to women studying. The minister approved the applications (in six days) of mathematician Grace Chisholm Winston (1868–1944) and physicist Margaret Eliza Maltby (1860–1944). After that, the Kurator resigned. In later years, Klein again asked the minister for permission for other female mathematicians, such as Annie Louise MacKinnon (1868–1940) and Isabel Maddison (1869–1950). In 1895, there were nine female mathematicians at Göttingen, who formed what could be considered the first "association" of female mathematicians.

David Hilbert arrived at Göttingen in 1895 and was also a defender of women's rights to study. He supervised the doctoral theses of six female mathematicians, three of whom came from the Bestuzhev Courses in Saint Petersburg, the main institution of higher education for women in Russia and whose teachers included the famous chemist Dmitri Mendeleev (1834–1907), who abandoned his position at the university in defense of the students. One of them was Vera Lebedeva (1880–1970), who was able to become a professor at the University of Iași in Romania, at the same time as her husband, the mathematician Alexander Myller (1879–1965), which would not have been possible elsewhere at that time.

Klein argued in Parliament and other institutions that women were just as capable as men and highlighted the obstacles they faced. In 1908, Prussia enacted new laws allowing the official enrollment of women in universities and the establishment of new secondary schools for girls. The educational reform, known as the Klein Reform, led to an increase in female students and the opening of professional opportunities for women: thus, one of Klein's daughters was principal of a secondary school for girls teaching mathematics and physics, while another daughter of Runge was an industrial mathematician at OSRAM and Telefunke.

However, laws continued to exclude women from university teaching positions in Prussia until 1920. In 1915, the illustrious mathematician Emmy Noether (1882–1935) was endorsed in her Habilitation, a requirement for teaching, by Hilbert, Klein, Runge, and Constantin Carathéodory (1873–1950), among others [59,60]. Hilbert was especially involved, arguing to those who opposed that "I do not see that the sex of the candidate is an argument against her admission. We are a university, not a bathhouse" [61] (p. 126). However, it was not until 1919 that Noether obtained the Habilitation, after Klein contacted the Minister of Culture again. Nevertheless, Noether's positions at the university were very precarious, and she was never able to obtain a professorship in Prussia. In 1923, the famous mathematician Richard Courant (1888–1972) managed, through administrative subterfuge, to pay Noether, even if modestly. In 1930, the renowned mathematician Hermann Weyl (1885–1955) tried to improve Noether's employment situation through the Ministry, without success.

Many sexist comments have been preserved in relation to Noether, about her physique or clothing, which is not the case with male scientists. For example, Edward James McShane (1904–1989) made the following sexist remark to Albert Tucker (1905–1995): "You know how you can tell a penguin from Emmy Noether? A penguin doesn't have a briefcase" [62] (PMC6-8). Tucker found such a "description" of Noether fitting [62]. Allies must intervene in these kinds of situations.

2.1.5. Other Mathematicians as Allies

Another famous mathematician who supported female mathematicians with his cordial treatment was Hermann Schwarz (1843–1921). In 1872, at Eidgenössische Technische Hochschule Zürich, Schwarz had the mathematician Elizaveta Fedorovna Litvinova (1845–1919) as a student (she was the only woman at the institution). Schwarz tutored her in some cases at his house, and he also invited her to have tea or spend an evening with his family [63]. Litvinova's doctoral thesis was supervised in 1879 by another famous mathematician, Ludwig Schläfli (1814–1895). Later, Schwarz had the illustrious Hilda Hudson (1881–1965) as a student at the University of Berlin. Hudson was the first female mathematician to participate (Laura Pisati had previously been invited, but tragically died in 1908, before the congress) in an International Congress of Mathematicians (ICM) in 1912. She earned the Order of the British Empire [64].

Examples of anti-discriminatory actions by various male mathematicians or scientists/technologists in defense of women or some female mathematician are summarized as follows. (a) The eminent John Stuart Mill (1806–1873) asked the memorable mathematician and astronomer Mary Somerville (1780–1872) [65] to be the first signatory of a mass petition to the British Parliament to give women the right to vote in 1868. (b) After numerous protests, the prominent physicist Paul Ehrenfest (1880–1933) managed to change the rule that women could not attend the mathematics club at Göttingen. Thanks to this, the prominent mathematician Tatiana Afanásieva (1876–1864) was able to attend; however, we should be cautious about using him as a role model due to the fact that he shot his son with Down syndrome, Wassik, before committing suicide [66]. (c) The distinguished mathematician Richard von Mises (1883–1953) did not want to remain at the University of İstanbul [67] after the contract at this university of the illustrious mathematician Hilda Geiringer (1893–1973) was not renewed. (d) The mathematician Jean Pierre Serre (1926), winner of the Fields Medal and Abel Prize, supported the research of his wife, chemist Josiane Serre (1922–2004), writing a mathematical text needed for the development of her research [68]. (e) Three months after being elected Rector of Carlos III University of Madrid, the distinguished statistician Daniel Peña (1948) promoted approval by the Governing Council of that university of Measures to support research for effective equality between men and women at Carlos III University of Madrid in 2007 [69], pioneering measures that many universities are still far from adopting today. (f) During his time as Minister of Science in Spain, the astronaut Pedro Duque (1963) canceled his participation in a scientific workshop—its organization was the responsibility of the presidents of the royal Spanish societies of physics, mathematics and chemistry—due to the disproportion in the sexes of the speakers [70], and this meeting was canceled. More male scientists have decided to refuse to participate in "manels" [71–73]. (g) Carlos Dorce, professor of the History of Mathematics at the University of Barcelona, integrated the gender perspective into the History of Mathematics subject [74].

2.2. Physics

In recent years, teaching experiences or Final Degree Projects [75] have been published that integrate the biographies of female scientists into the university content of physics and engineering subjects. However, these biographies do not usually highlight the support that some of them received from their partners or mentors, missing an opportunity to talk about family conciliation, co-responsibility, or the transmission of egalitarian models. Therefore, we will comment below on how we can include these aspects, starting with the topic of radioactivity, which is taught not only in the subjects of the Physics and Chemistry degrees but as part of the syllabi of other first-year subjects of Biology or Biotechnology degrees. We must highlight that there have been very important contributions in this field beyond Marie Curie, the best-known female scientist in the history of science.

2.2.1. Radioactivity

Marie Curie (1867–1934) was the first person to win two Nobel Prizes in the history of science and, sometimes, she is the only female scientist known by students. However, they are probably unaware that, throughout her career, she faced numerous problems for being a woman and a foreigner, and "she did not get ahead alone. As with other women in science, her family environment played a determining role in her professional career (. . .) and, above all, in the unconventional family model that she adopted with Pierre Curie" [76] (p. 14). Curiously, Pierre Curie (1859–1906), her sentimental and scientific partner, had written in his diary "women of talent are rare" before meeting her. And as Roqué [76] (p. 15) pointed out,

> Although we have barely heard Pierre Curie's voice, there is nothing to indicate that he did not also gain from these arrangements. A conventional marriage would have left him more time for research, but he would have deprived him of sharing it with his partner. . . The experience of the Curies can be valuable today not only for women, but also for men of science.

Pierre's role was crucial in the recognition of Marie's work, as he refused to accept the Nobel Prize in Physics in 1903 if she was not included. This refusal and the support of the mathematician Gösta Mittag-Leffler, who warned them of what the Nobel committee was up to, managed to get the Swedish Academy to include her in the award. And another of her fundamental supporters was her father-in-law, Eugène Curie, who first took care of her eldest daughter Irène so that they could work and then, when Pierre died, he continued to help her care for her two daughters. Five years after the death of her husband, Marie Curie began a relationship with Paul Langevin (1872–1946), who was then a married man. The publication of the letters exchanged in this relationship unleashed a campaign against Marie Curie and led the mathematician Paul Appell (1855–1930), dean of sciences at the Sorbonne, to encourage a group of professors from that university to demand that Marie leave France. Thanks to his daughter, the feminist writer Marguerite Appell, who was mentioned earlier when talking about Borel, this initiative was stopped. Meanwhile, "no one asked Langevin to leave the university, although in reality he was the adulterer" [77] (p. 85). Fortunately, her brother-in-law, Jacques Curie, and scientists such as Jean Perrin (1870–1942) and André Debierne (1874–1949) also supported her in these terrible times. But the controversy reached the Nobel committee, and even Svante Arrhenius (1859–1927), secretary of the committee, who initially encouraged her to attend, asked Marie Curie to stay in France and not attend the ceremony, while Mittag-Leffler advised her otherwise [78]. Finally, she attended the Nobel Prize ceremony, but the damage caused by the attacks was so great that she suffered a major depressive episode that kept her away from work and her daughters for a year, and it was Debierne who took care of the laboratory and supervised the care of the girls. Her friend Hertha Ayrton, who will be introduced later, also helped her recover [79].

Her daughter Irène Curie (1897–1956) and her husband Frédéric Joliot (1900–1958) followed in her footsteps and also achieved the Nobel Prize in Chemistry for the discovery of artificial radioactivity, sharing both laboratory and family work, maintaining an equalitarian relationship and both signing with the surname Joliot-Curie [80]. Likewise, upon receiving the Nobel Prize, to show that they had contributed equally to the discovery, Frédéric presented the chemistry part and Irène the physics part [80]. The couple also shared their political commitment and were both involved in the anti-fascist struggle, which would make them members of the communist party [78]. Both would have political responsibilities, Irène as Undersecretary of State for Research in the government of Leon Blum and Frédéric as Director of the National Center for Scientific Research (CNRS) and the Commissariat for Atomic Energy (CEA), a position from which he would later be dismissed for being a communist and opposed to the use and development of nuclear weapons [78]. Both of them died early from cancer, probably due to a lack of precautions in their exposure to radioactive substances, as also happened to Marie Curie. These and other early deaths would help us talk in the classroom about accidents related to nuclear energy used for civil purposes.

In addition, we must highlight the important presence of women as permanent researchers both at the Radium Institute in Paris and at the Institute for Radium Research in Vienna. In this last case, both the figure of director Stefan Meyer (1872–1949) and political context are important, because as Rentetzi [81] (p. 389) emphasized, "in large part, women's active participation in laboratory life at the Radium Institute can be credited to Meyer's progressive politics, coupled with and encouraged by the political context of Red Vienna". And also, Rentetzi [82] pointed out how the support of important physicists such as Franz Exner (1849–1926), Ernest Mach (1839–1919), and Viktor von Lang (1838–1921), who founded a committee to support the admission of women to university studies, contributed greatly to creating an enabling environment for women in this field.

2.2.2. Nuclear Physics

Scientific collaboration between men and women has been very common in the history of science; in fact, Margaret Cavendish (1623–1673) "recommended women who desired to study and conduct research in natural philosophy to make sure they married 'the right man' ". [83] (p. 93). This collaboration has been very positive [80]. However, working as a couple also has risks for women, as the Matilda effect shows us. The historian Margaret Rossiter, to whom we owe this term, used it to point out the lack of recognition experienced by female scientists who carried out their research with male colleagues and partners, with or without romantic ties. As Donald [38] showed, one of the scientists who suffered the Matilda effect was Lise Meitner (1878–1968), the scientist who "promoted and guided the study that led Otto Hahn and Fritz Strassmann to discover nuclear fission" [84] (p. 78) and yet did not receive the Nobel Prize for this discovery. Otto Hahn (1879–1968), her friend and research partner for more than thirty years, appropriated the Nobel Prize [84], an award contested by other scientists such as Niels Bohr (1885–1962), who "understood that Meitner and Frisch, and also Strassmann, should have been included" [85] (p. 267). But in addition to this betrayal, it is fair to recognize that physicists such as Ludwig Boltzmann (1844–1906) had great importance in Meitner's life and "accepted women as official students, since he was totally contrary to gender discrimination" [86] (p. 57). As Rentetzi [82] (p. 17) showed, "Boltzmann supported the Association for Extended Women's Education with his full membership. In the mid-1870s, when Henriette von Aigentler, the woman who later became his wife, was refused permission to unofficially audit lectures at the University of Graz, Boltzmann encouraged her to appeal". Also, Max Planck (1858–1947), who, unlike Boltzmann, was not in favor of women entering the university, would be her mentor and support her in her career. As Sime [87] (p. 68) stated,

> She remembers how unusual it was "for a girl to attend university lectures at all," but in Boltzmann she had a brilliant teacher who inspired her to pursue a life in physics. In Berlin in 1907 she found that Max Planck did not favor higher education for women, but five years later he made his assistant, her first paid position.

In the late 19th century, Arthur Kirchhoff invited leading university professors and intellectuals to discuss the admission of women to German universities. In the responses, we can see that famous scientists such as Felix Klein, mentioned above, advocated better educational opportunities for women:

> Mathematicians unconditionally favored the admission of women: Felix Klein reported that his six current women students (fully enrolled in Göttingen under a trial program open only to foreign women) were as capable as the men, while the Kiel mathematician G. Weyer listed twenty-one women mathematicians and astronomers from Hypatia to Maria Mitchell, including a biography of Sofia Kovalevskaia. [88] (p. 29)

But others, such as Max Planck, also expressed deep prejudices about women's academic work [89,90]. In the early days of nuclear physics, there were scientists such as Ernest Rutherford (1871–1937), who favored the entry of female scientists into research; others such as J.J. Thomson (1856–1940), B. Boltwood (1870–1927), and F. Soddy (1877–1956), who were tolerant of their presence; and finally, those who hindered their careers, such as Emil Fischer (1852–1919), Max Planck, and Otto Hahn [91]. The supportive attitude of Rutherford toward his female physics researchers, in particular Harriet Brooks (1876–1933), or female physics graduates was studied by Rayner-Canham and Rayner-Canham [92], but Greenstein [93] also showed that this was not the case of Cecilia Payne (1900–1979), who was regularly humiliated in class by this famous physicist.

In Spain, in the era known as the Silver Age, we must recognize the role of Enrique Moles (1883–1953), who "always surrounded himself with female collaborators and played an active role in promoting their scientific status. This attitude was reflected in his support for them to be part of the SEFQ and also in his publications. Many of his works were co-authored with them" [94] (p. 99). Finally, it is important to mention the team that discovered meitnerium in 1982, led by physicists Peter Armbruster (1931) and Gottfried Münzenberg (1940), for proposing the name for element 109 on the periodic table in order to recognize the Lise Meitner's decisive role in nuclear fission [95].

The second woman to receive a Nobel Prize in Physics was Maria Goeppert (1906–1972), who was fortunate to grow up in the university environment of Georgia Augusta University, known as Göttingen, one of the most famous universities in Germany, where, as previously explained, illustrious mathematicians such as David Hilbert taught and from which came numerous Nobel Prize winners such as Max Born (1882–1970), who invited her to join his physics seminar [96]. She was encouraged by her father to pursue a scientific career from a young age, and she would later have the support of her husband, chemist Joseph Edward Mayer (1904–1983), and also the backing of physicist Enrico Fermi (1901–1954), who would follow her research closely [80]. Fermi had worked at the Royal Physics Institute of Via Panisperna in Rome, where there had been a female presence since its origins thanks to the physicist Pietro Blaserna (1836–1918), who, like mathematicians Vito Volterra (mentioned in the mathematics section) and Giuseppe Peano (1858–1932), accepted female students [97]; there, Fermi met his wife, writer and activist Laura Capon (1907–1977). Regarding Fermi's attitude, we cite the words of her student, the prestigious physicist Mildred Dresselhaus (1930–2017):

> The other thing about it, with him, it was about what you did; it wasn't what you looked like. Being a woman in physics didn't matter because, in Italy, women had been doing science for many years, but he was much more liberal than most. Not everybody [had the same experience] because I have talked to other Italian women, they have told me how difficult it was to be an Italian woman in physics. [My only experience was with] him, and for him it was what you did and not what your sex happened to be. [98] (p. 2436).

After her marriage, Maria Goeppert moved to Baltimore in the United States, where her husband had obtained an academic position at Johns Hopkins University. However, she had difficulties getting a job there because she was the wife of a university professor, since the law against nepotism prohibited the hiring of two members of the same family, something that, in practice, always affected married women [99]. Thanks to Karl Hertzfeld (1892–1978), Goeppert became an informal member of the department, where she worked for free, but at least, she could mention her affiliation to this university in her articles. In 1939, they had to leave this university, which had decided to reduce faculty staff due to financial problems. They went to Columbia University, where her husband got a job but she did not. In 1940, the book they wrote together, titled *Statistical Mechanics* [100], was published and would become a reference in this field of research, but the faculty objected to her name appearing on the cover [80]. Thanks to Harold Urey (1893–1981), who got the university to allow Goeppert to teach some unpaid chemistry classes, her name and affiliation were able to appear in the book. Finally, in 1941, Goeppert received her first paid job offer, as a part-time professor at Sarah Lawrence College. And in 1942, thanks to a collaboration with Fermi, she joined the Manhattan project, which sadly led to the dropping of nuclear bombs on Hiroshima and Nagasaki in 1945. About this period, Goeppert would later comment on her relief at not having contributed to the development of the bomb [80]. It is important to remember that Lise Meitner, whom we talked about previously, did not want to participate in this project [86], and many scientists later regretted their participation in it. After the end of the war, the couple were hired by the University of Chicago, although Goeppert still received no salary. It was there that she carried out research on the layered structure of the nucleus of the atom that would lead her to receive the Nobel Prize. As an anecdote, it should be noted that a local newspaper announced the news of Maria Goeppert's Nobel Prize as follows: "A mother from San Diego wins the Nobel Prize in Physics" [99].

2.2.3. Electricity

In the field of electricity, the work of Hertha Ayrton (1854–1923) stands out. Hertha Ayrton, an engineer, inventor, and scientist, as well as a suffragist from a Jewish family and of humble origins, had the support of other women in her career, especially the feminist Barbara Bodichon (1827–1891) and her husband, the physicist and electrical engineer William

Ayrton (1847–1908), who was favorable to the education and legal rights of women [101]. However, Hertha's domestic responsibilities and caring for her young daughter left her little time to continue researching and working. Thanks to the inheritance left to her by her protector, Barbara Bodichon, Hertha Ayrton was able to hire a housekeeper and dedicate her time to research [102]. The lack of co-responsibility of men in care and household chores is something that still continues to hinder the careers of female scientists, as we saw recently with the COVID-19 pandemic [103], and this is a good example to show the inequalities that affect female scientists in the classroom. On the other hand, unlike the Curies, William and Hertha did not research together, although they carried out their research work in the same laboratory, because William wanted to avoid any misunderstanding with the authorship of Hertha's findings. Similarly, Margarita Salas (1938–2019) and her husband Eladio Viñuela (1937–1999) separated their professional careers when they returned to Spain in 1967, so that each member of the couple earned merit for their own work [55]. Hertha's work on the electric arc was received with great interest and increased her prestige, enabling her to become the first female member of the Institution of Electrical Engineers (IEE). In 1902, she was proposed as a member of the Royal Society by engineer and mathematician John Perry (1850–1920), but she was not accepted because her husband was already a member, and they considered the couple a single entity [104]. These facts serve to highlight the roles of allies such as that of astrophysicist Norman Lockyer (1836–1920), the first editor and founder of the famous magazine *Nature*, who was married to the prominent suffragist Mary Brodhurst Lockyer (1852–1943) and would support the admission of women into societies through his publication [8]. In the meantime, William Huggins (1824–1910), then director of the Royal Society, feared that women would "trivialize" his elitist scientific institution [101,105]. However, William Huggins collaborated with his wife, Margaret Lindsay (1848–1915), an astronomer and a pioneer in the field of spectroscopy, with whom he would write an atlas [106]. As Schiebinger [107] (pp. 29–30) highlighted, Margaret Lindsay is an example of talented women who "contributed quietly to their husbands' careers, a phenomenon that persists even today. Only occasionally did a woman, such as the X-ray crystallographer Kathleen Lonsdale, enjoy a husbandly assistant". We can also use these facts in class to highlight that, despite the support of the founder of the *Nature* magazine, Norman Lockyer, for the entry of women into science, this magazine maintained the offensive term "man of science" until 2000, ignoring physicist Norman R. Campbell's (1880–1949) request in 1924 to change it to the more inclusive term "scientist", a term "coined nearly one hundred years prior by William Whewell, in his review of an astronomy article by Mary Somerville" [8] (p. 4). And we had to wait until 2018 for this magazine to hire its first female editor-in-chief, geneticist Magdalena Skipper (1969) [8].

2.2.4. Astronomy

In astronomy, we must remember that women have sometimes been hired for scientific work not because of progressive ideas but because they were paid less, as was the case of female astronomers at Harvard. The physicist Charles Pickering (1846–1919) "was convinced that women, less intellectually qualified than men, nevertheless had more patience and a higher level of attention" [55] (p. 128). However, contrary to his ideas, some of them made discoveries that changed astrophysics forever, such as Annie Jump Cannon (1863–1941), Cecilia Payne-Gaposchkin (1900–1979), and Henrietta Leavitt (1868–1921) [108]. Although it took years for the Nobel Prize to be awarded to a woman in this field (the Nobel Prize in Physics was awarded to Andrea M. Ghez (1965) in 2020 for her work in astronomy), there were women who deserved it previously. Gösta Mittag-Leffler sent a letter to Henrietta Swan Levitt to inform her of his intention to nominate her for the Nobel Prize when she had already died. This is a prize that is only awarded to living people, and therefore, it could not be awarded [55]. It was also not awarded to Jocelyn Bell (1943) in 1974 for the discovery of the pulsar, but it was awarded to her thesis supervisor, Antony Hewish (1924–2021). And as Donald asked, "was she ignored because she was a woman? Or because she was junior and 'merely' collecting data, whereas Hewish had the scientific track record and was the project lead? It's not easy to disentangle" [38] (p. 54). Vera Rubin (1928–2016) did not obtain the Nobel Prize either, although her work provided the most direct and robust evidence for the existence of dark matter.

Vera Rubin was an astronomer who, as we will show below, was lucky to have the support of her (Jewish) family and her partner, the physicist Robert Rubin (1926–2008). Nevertheless, she faced hurdles in advancing her professional career. Since high school, she had problems studying astronomy because her teachers or classmates did not consider it an appropriate discipline for a woman. Even so, she persisted and obtained her degree at Vassar University, which was one of the Seven Sisters Colleges, an association of American universities for women, where Maria Mitchell (1818–1889), a reference for Vera Rubin, taught. After marrying Robert, she tried to pursue a doctorate at Princeton, but she was rejected for being a woman and she decided to pursue it at Cornell University instead. Her master's thesis on the movement of galaxies in space was not well received by the head of the astronomy department, but even so, and with a one-month-old baby, she presented it at the American Astrophysical Association conference, where she received numerous criticisms from the association's members [55], with the exception of Martin Schwarzschild (1912–1997) who, as Vera herself narrated, said what should be said to a student "This is very interesting, and when there are more data, we will know more" [109] (p. 4). After finishing her master's degree, Vera Rubin and her family moved to Washington for her husband's job, and during this period, she seriously considered leaving astronomy [110]. After six months, encouraged by her husband, she enrolled in a doctorate at Georgetown University thanks to the logistical support of her entire family. At Georgetown Observatory, she felt supported by the driving force behind the astronomy doctoral program, Father Francis J. Heyden (1907–1991), a Jesuit astronomer who had fostered an inclusive department [110]. She also had the support of George Gamow (1904–1968), who would be her thesis supervisor. This contributed to the approval of her doctoral work in 1954 [55], in which she concluded that galaxies were grouped together rather than being distributed throughout the universe by chance, an idea that was rejected and that would take two decades to be accepted [110]. In 1963, she began collaborating with the astronomer couple Geoffrey (1925–2010) and Margaret Burbidge (1919–2020), whom Vera admired and with whom she made her first observations of the rotations of galaxies. Two years later, she would join the Carnegie Institute of Science, where she would meet astronomer and instrument maker Kent Ford (1931–2023), with whom she began work related to her controversial thesis on galaxy clusters. The results of this investigation, in which six students participated, were published, including their names, thanks to the tenacity of Vera Rubin, who threatened the journal, which was reluctant to include them, with withdrawing the publication [55]. In addition to her key role in the detection of dark matter when observing the spinning of galaxies, we must highlight, from her biography, her fight for the recognition and inclusion of women in astronomy [111].

Through the biographies of these women who were pioneers of physics and engineering, we have shown the important roles that some men played in the consolidation of their scientific careers. These contributions are important because, in the world of science and particularly in physics, misogyny and sexism have prevailed for centuries, as Evelyn Fox Keller's story [112] (p. 11) showed us about her doctoral experience in theoretical physics at Harvard, which she described as "two years of almost unmitigated provocation, insult, and denial". Misogyny is present in the speeches of Richard Feynman [113], who "represents physics after the disaster, after our participation as a profession in the development of the atomic bomb (. . .) The irresponsible physicist" [114] (p. 185). And it is important to note that some of these misogynistic discourses can be used to combat them. For example, after analyzing the words of mathematician Gino Loria (1862–1954), who attributed the successes of scientists such as Hipatia or Kovalévskaya to their environment, Govoni [115] (p. 289) showed her agreement in that the environment is important:

> Just like men, in order to succeed in science and mathematics women must grow up in a family that—at the very least—does not destroy their potential. In

> addition, or alternatively, they need teachers, friends, colleagues or partners who support them as equals. In other words, women need to be admitted into that select circle that the founders of the Royal Society called the "invisible college". . . . If you are not accepted into that college or network—which is always personal, institutional, and political at the same time—it is impossible to make science and/or have a place in its history.

As Govoni suggested, to support equal opportunities in science and mathematics, we have to begin by strengthening the image of science as culture and, secondly, "to work much more on boys and men than on girls and women" [115] (p. 311). And this is what we intended in this work, to retrieve positive references that we can show to our students, among which we could also include physicists Tomas Brage [116], professor of physics and expert in gender equity and equal opportunities, and Paolo Giordano, the author of *Tasmania* [117], a novel where sexism in physics is also discussed.

3. Conclusions

Throughout this paper, the importance of support and denunciation from the group with power, the privileged group, in this case, white heterosexual men [118], in eliminating obstacles for female physicists and mathematicians was demonstrated. Likewise, the significance of co-responsibility was revealed, from which we are still far away today within the academic world [10]. Examples of male allies were also shown, including notable physicists and mathematicians who can be used in classes as counter-stereotypical gender role models, that is, with gender-incongruent roles, in order to break down stereotypes and promote non-traditional behaviors [119], especially in men in STEM subjects. However, it is advisable to have models of close allies, especially among teaching staff.

Unfortunately, gender stereotypes are still in force in science and are transmitted even in primary mathematics textbooks [120]. To change this situation, the involvement of the scientific community is necessary, especially those who hold power and therefore have a more influential voice and greater strength to oppose discrimination [26]. Furthermore, the messenger is key, as there are men who are not willing to listen to the message of gender equality if it comes from women but who are willing to listen to it if another man is the messenger [121]. Therefore, it is important to promote spaces and meetings where conversations can be held about the inequality present in the scientific community, both to generate empathy and increase awareness and to learn about the successes of other defenders of equality [122]. These meetings would also serve to keep allies engaged, since they must believe that their efforts are important [123], which is why in some universities, there are programs such as Advocates and Allies at North Dakota State University [124]. Note that becoming an ally is a lifelong process, with iterative cycles of understandings and action [125]. We also want to highlight that the perceptions between men and women on the support needed to achieve equality are different; men believe that they are great allies in the workplace, while women disagree [126]. Consequently, as indicated by the Association of Women in Science, it is advisable for a good ally to listen to women [127]. More recommendations for men are available in [128,129], which highlight the importance of the active participation of (cis-white) men as allies in changing the current culture, in both day-to-day settings and the big picture. Some acts of allyship commented in this paper were supportive of many women, but others were supportive of just one woman, who perhaps was seen as an "exception" to generalized stereotypes. Therefore, we must be cautious so that male students do not think that individualized actions are enough, or that they are doing enough by helping the women in their immediate orbit, rather than focusing on institutional change.

Although we focused on universities, our contribution can also be implemented in high schools. Note that using the history of science provides a richer context to learn not only science but also the interactions between society and science and scientists [130].

Regarding how to incorporate historical figures together with actual and close role models in mathematics and physics, different ways can be considered. For example, we can introduce the biography of the figure who is an expert in each field before working in that field, as proposed by Figueiras et al. [58], or use Wikipedia tasks [131]. More proposals are explained by Epifanio et al. [132], such as using quotes of the figures at the beginning of a unit to initiate a short discussion, to include them in problems, to investigate different figures as tasks or to use gamification, such as through digital escape rooms [133]. For resources about female mathematicians and physicists, you can see [134,135], respectively. As many male figures appear in these disciplines through laws, rules, theorems, results, etc., we think it is recommendable to include more women and other minorized groups than male allies for balancing. Nevertheless, including the contributions of women and other minorized groups together with male allies should not be an isolated fact neither in terms of time (it should not constitute the action of a single isolated day) nor as a unique action, i.e., our teaching should take into account diversity in all facets, such as classroom management, contents, evaluation, etc. The guides for mainstreaming gender in university teaching in physics [135] and mathematics [134] contain recommendations on those aspects.

As future work, the impact of presenting these male allies as references in university classrooms could be analyzed. This work constituted the first but essential step, which is the compilation of allies in physics and mathematics since they are unknown to the vast majority of teachers in these fields. This was demonstrated by the result of a survey carried out among university professors in these fields during a training course on teaching with a gender perspective in mathematics at Jaume I University in January 2024, in which the participants were unable to provide any names. It should be noted that the compilation carried out here is not exhaustive, but it was intended as a starting point for recovering hidden male allies in these and other scientific fields.

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