# Rebalancing the historical female under-representation in education

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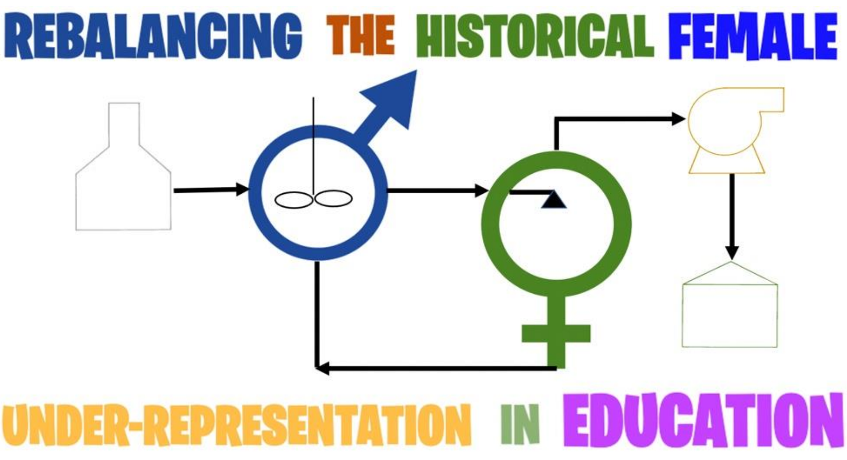
## ■ ABSTRACT

Women are increasingly present in the field of engineering, and despite a significant female presence, it has been found that the programmes continue to make no reference to women scientists. In chemical engineering, for example, all the names of scientists mentioned in the programmes belong to men only. To test this hypothesis of the over-representation of men in the programmes, a series of random opinion surveys were launched among 600 students from 5 universities to find out whether they had noticed this over-representation and what they thought about it. The results showed that the vast majority did not realize that the scientists presented as examples in classes were all men. In fact, 90% of the student panel were unable to identify a woman in the chemical engineering field, and the remaining 10% could cite only one or two – who were among the most recent and had received most attention from the media. The issue of inequalities between girls and boys and between women and men in education remains central to understanding and combating gender inequalities and to enabling people to develop as persons free from the limitations imposed on them by gender stereotypes. However, these inequalities cannot be explained exclusively by the issue of access to education but must also take the type and content of education into account. This article is a call for reflection on the content of university curricula and has a twofold objective: on the one hand, to raise awareness of this imbalance in representation among students, both male and female, and, on the other hand, to launch reflection on this "invisibility of women" and to propose some avenues for debate.

## ■ GRAPHICAL ABSTRACT




## ■ KEYWORDS

General Public < Audience; First-Year Undergraduate / General < Audience; Second-Year Undergraduate < Audience; Upper-Division Undergraduate < Audience; Graduate Education

/ Research < Audience; Chemical Engineering < Domain; History / Philosophy < Domain; Public Understanding / Outreach < Domain

## ■ INTRODUCTION

DEIR (Diversity, Equality, Inclusion, and Respect) aims to ensure equal treatment and opportunities for all people by eliminating prejudice and discrimination[1,2]. The existence of a diversity deficit in the fields of Science, Technology, Engineering, and Mathematics (STEM) has prompted a lot of research and discussion about how to create a more diverse student body and workforce.  The existence of a diversity[3–7] deficit in the disciplines of Science, Technology, Engineering, and Mathematics (STEM) has prompted a lot of research and discussion about how to create a more diverse student body and workforce. All students gain from connecting with various viewpoints when STEM faculties understand how to make use of diversity[8]. Some authors have developed breakfast discussions about the success of women in science,[9] and team-based poster conference activities[10] in order to give first-year chemistry students a framework to discuss inclusion and diversity, while others have developed activities relating to the colour of CPK[11] model molecules and national flags to open discussion on diversity and geopolitics.[3] Also noteworthy are some engaging challenges or contests to promote women in science[12–14]. To cultivate an equitable and inclusive environment[15], instructors can exercise critical self-reflection on a regular basis, focus on students' strengths rather than their deficiencies, develop a connection with each student as a person, employ best practices to engage a diverse student body, and recognize students' potential as scientists.[16] In this way, instructors would give greater responsibility to students as future contributors to a fair society. In order to achieve equality, diversity and inclusion in our universities, there is a need to evaluate the figures currently used as examples in learning material[17]. Many researchers have pointed out the small number of female figures used in STEM textbooks[18–21] (9% in Biology, for example[17]) or other disciplines (10% in economics[22]). A recent study examined gender representation in several college-level general chemistry textbooks[23]. On average, females were found to make up 30% of images but only 3% of the named scientists (a male name appears once in every four pages of text, on average, while a female name appears once in every 250 pages of text). This study concluded that male over-representation in chemistry textbooks reflected and perpetuated unconscious gender bias in STEM as proposed by researchers[24]. Gender imbalance was ubiquitous among all publishers examined and observed in both traditional and electronic texts. Such observations are alarming, as women have made enormous contributions to the field of chemistry.[25] Seven of these women have received Nobel Prizes: Emmanuelle Charpentier & Jennifer A. Doudna, 2020; Frances H. Arnold, 2018; Ada E. Yonath, 2009; Dorothy Crowfoot Hodgkin, 1964; Irène Joliot-Curie, 1935; Marie Curie (née Skłodowska), 1911. While the number of women in chemistry (college level) is around 38%[26] in the US, the number of women in chemical engineering is lower, even though it has been increasing steadily over the years to reach graduating classes of chemical engineers that are around 30 to 35 percent female[20,27]. The number of women cited in chemical engineering textbooks is even lower than in chemistry. A quick analysis of the chemical processes taught in our universities revealed that, of the hundreds of processes mentioned, 4% are named after a location (city, region, etc.), 6% after a technological reference (contact, pressure, lead chamber, etc.), 10% after the name of the molecule produced, 15% after a company (UCB, Stamicarbon, Total, Solvay, BASF, etc.) and 65% are named after the scientist who invented the process. Dramatically, among these scientists, the proportion of women is equal to 0%. This can sometimes be explained by the date of the discoveries, which were made between 1750 and 1935 when the percentage of women in science was much lower than today. Nevertheless, a significant part of differences between the actual proportion of women in the general population and their absence in learning could be explained by cases of women scientists being ignored, denied credit, or dropped from sight. This phenomenon is named the 'Matilda Effect',[28] an expression invented for the New York suffragist and feminist critic Matilda J. Gage , who both experienced and articulated this phenomenon in the late nineteenth century.

Most of the processes discovered since 1945 have been patented by companies or by a large number of inventors, resulting in the end of the opportunity for inventors to give their names to processes. In the same way that women have been historically[25] and currently engaged in chemistry and chemical engineering, they will continue to make significant contributions in the years to come but, as the processes of tomorrow will no longer be named after their inventors, it will be impossible for male over-representation to become balanced naturally with time. Increasing the representation of women in academia is a challenging priority in higher education policy[29] and, if universities are to take up this challenge, it is important to highlight women scientists as role models. In this context, the purpose of this study is to initiate debate and encourage reflection on (i) what impact such male over-representation has on chemical engineering and chemistry students' impressions and feelings, (ii) what can be done to redress the imbalance in gender representation, and (iii) what can be proposed to educators to take this imbalance in the representation of male and female scientists into account.

## ■ COLLECTING STUDENTS' OPINIONS

Students from five universities in France: the University of Lorraine, Aix-Marseille University, the University of Rennes, INSA Rouen Normandie, and the University of Toulouse, and from different fields (chemical engineering and chemistry) were contacted and surveyed (Table 1). Professors from these different universities invited students to evaluate their feelings about scientific figures used in their courses by completing an anonymous online survey in French containing thirteen questions and a free response section. Most of these questions were multiple choice or questions with responses based on a Likert[30] scale. The forms were built online with Google forms[31] (free survey administration software), a specific form being created for each university and for each field taught in that University (Chemical Engineering and/or Chemistry). This resulted in the creation of 2 surveys (one in Chemistry and one in Chemical Engineering), as presented in Figure 1. The levels of the students, and the number of students per university and field are listed in Table 1.

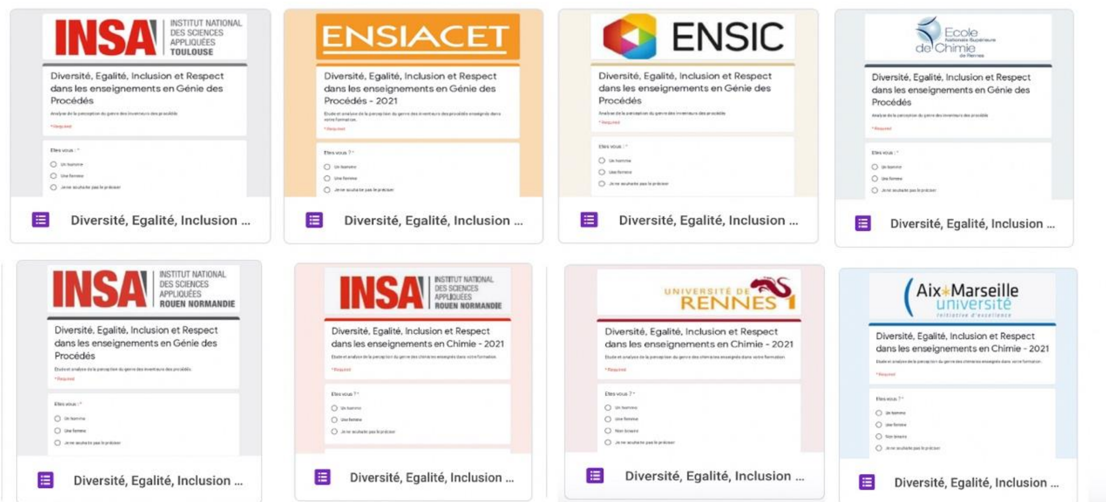


**Figure 1.** Sample of the survey forms used between December 2020 and March 2021.

A total of 594 students of either Chemical Engineering (425 students 2020/2021) or Chemistry (169 students 2020/2021) participated in this study. The response rate was evaluated at around 29% of the total number of students contacted. The number of students per university is detailed in Table 1. The first question of the survey (Q1/13 – N = 594), asked each participant to define their gender. Results are reported for each university in Table 1. Globally, 58.3% of the participating students were women, 40.0% were men and 1.7% did not want to state. The percentage of women was slightly higher than the proportion of women enrolled in the courses. This demonstrates the interest that women have in this study but constitutes a first potential bias in this research.

The second possible bias is that the study was framed within the context of binary definitions of sex and gender. The use of the terms male and female is overly simplistic and does not capture the diversity of human sex and gender[32]. Therefore, due to the over-representation of females in our panel and the multiple definitions of sex and gender, there was a potential impact of human bias in this study. All data were collected anonymously with the agreement of the General Data Protection Regulation (EU) 2016/679 (GDPR) and were validated by the corresponding office in some of the Universities involved in this study. All data were removed from Google form servers after their collection. Data for questions Q2 to Q13 are presented in Figures 2, 3, 4 and 5 and in the following section.

**Table 1.** Composition of the panel tested (academic year 2020/2021). (Q1/13 – N = 594).

| University, location | Discipline / Department | Level of study | Number of students surveyed/contacted | Percentages of men and women surveyed* |
|---|---|---|---|---|
| Institut National des Sciences Appliquées (INSA), University of Toulouse, Toulouse, France | Chemical Engineering & Environment | $4^{th}$ and $5^{th}$ year – engineering degree | **51** (108 contacted – 36% men and 64% women) | 25.5 % men and 72.5% women |
| École Nationale Supérieure Des Ingénieurs en Arts Chimiques et Technologiques (ENSIACET), University of Toulouse, Toulouse, France | Chemical Engineering | $4^{th}$ and $5^{th}$ year– engineering degree | **110** (234 contacted – 57% men and 43% women) | 39.1% men and 60% women |
| École nationale supérieure des industries Chimiques (ENSIC), University of Lorraine, Nancy, France | Chemical Engineering | $3^{rd}$, $4^{th}$ and $5^{th}$ year– engineering degree | **136** (430 contacted 45.3% men and 54.7% women) | 48.5% men and 50% women |
| École nationale supérieure de chimie de Rennes ENSCR, | Chemistry and Chemical | $4^{th}$ and $5^{th}$ year– | **83** | 36.1% men and 63.9% |

| | | | | |
|---|---|---|---|---|
| University of Rennes, Rennes, France | Engineering | engineering degree | (750 contacted, 40.0% men and 60.0% women) | women |
| Institut National des Sciences Appliquées (INSA), University of Normandie, Rouen, France | Chemical Engineering | 4th and 5th year– engineering degree | **45** (130 contacted, 50% men and 50% women) | 53.3% men and 46.7% women |
| | Chemistry | 4th and 5th year– engineering degree | **57** (180 contacted, 33.5% men and 65.5% women) | 38.6% men and 59.6% women |
| Institut Universitaire de Technologie (IUT) de Rennes University of Rennes, Rennes, France | Chemistry | 2nd and 3rd year - bachelor's degree | **53** (101 contacted, 35% men and 65% women) | 35.8% men and 62.3% women |
| Institut Universitaire de Technologie (IUT) Aix-Marseille University, France | Chemistry | 2nd and 3rd year - bachelor's degree | **58** (117 contacted, 36% men and 64% women) | 27.1% men and 71.2% women |
| Total | - | - | **594** (2040 contacted, 42% of men and 58% of women) | 40.0% men and 58.3% women |

* Total can be different from 100% when some students did not want to state or choose their gender (non-binary option).

However, it is important to notice that our study surveyed only French universities, where the percentage of women in the teaching staff is between 38 and 44% which can be notably higher than in other countries. It could be interesting to extend the survey to other countries in which the political and social environment regarding gender is different.

## THE DIFFERENT POINT OF VIEW OF THE STUDENTS

Students were first questioned about their knowledge in chemical engineering and chemistry. A list of thirteen named processes (for students in chemical engineering) or a list of twenty chemical reactions (for students in chemistry) was presented in the survey. The students were asked to tick the name presented if they had ever encountered it during their courses (Q2/13 – Figure 2 – N = 594). These lists were set up in agreement with the content of the courses of each field. Almost all students were able to recognize at least one name on the list (only 8% of chemical engineering students and 12% of chemistry students were unable to recognize any name on the list). Among the list of Chemical Engineering processes, the three most recognized named processes were the Fisher Tropsch process[33] (79.8%), the Solvay process[34,35]

(76.5%) and the Haber-Bosh Process[36] (46.1%). The names of the other processes are listed in Figure 2 with the percentage of recognition.

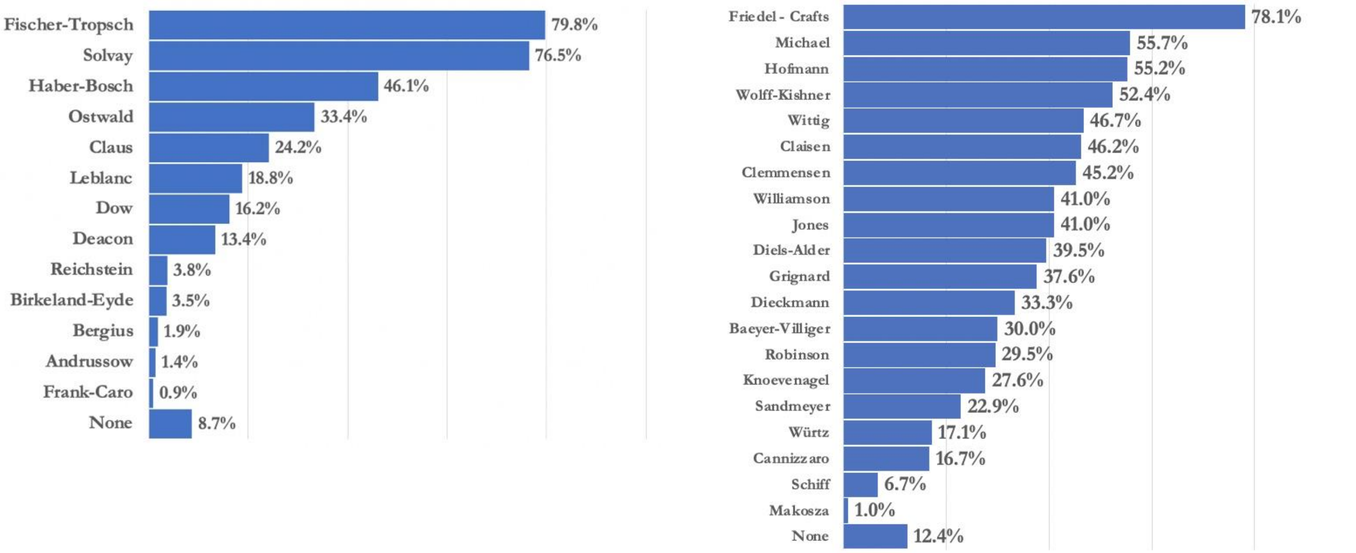



**Figure 2.** Second question of the survey (Q2/13): (left) best known processes named after scientists (among 425 students); (right) best known chemical reactions named after scientists (among 169 students).

These results are aggregated between the responses of the different genders, and it is possible to determine whether gender affects the responses or not. For example, among the 1184 responses concerning the ticked names of recognized processes, 22% of the women knew the Solvay process against 22.3% of the men; 7.5% of the men knew the Claus process against 7.4% of the women; 14.5% of the men knew the Haber-Bosch process against 13.7% of the women. These results were obtained considering the four Chemical Engineering universities, but it is worth noting that, if the analysis was carried out university by university, the results differed only slightly. Such statistically close results tend to show that general "Chemical Engineering" culture is only acquired through the curriculum, i.e., students' knowledge of the history of chemical engineering is limited before they enter university. This may be surprising, given that chemical engineering is at the heart of many current technological advances.

Students in Chemical Engineering were also asked how these names were chosen (Q2 bis – N = 110). According to the panel: 9.1% (men 12% women 8%) of the students thought the processes were named after the name of the end product, 35.3% after the name of the company that patented the process (men 26%; women 42%), 30% after the person who discovered/industrialized the molecule (men 55%; women 20%), 0% after a geographical reference, 23.6% after a technological reference (men 16%; women 29%). 1.8% of the students surveyed had no opinion. If we look at the responses by gender, a strong difference in the responses between men and women can be observed: while men associate the name of the process more with an inventor, women associate it more with the name of a company or a technological reference. In the end, great disparities can be observed between what the students thought gave the name to the process and reality. This difference in response between men and women is very interesting, because it shows, in a way, how women and men position themselves when it comes to being recognized and rewarded. We can put forward two hypotheses: the first is that women are more recognized through the family and community as mothers, daughters, sisters, etc., while men are more recognized through their individual value, as citizens. Therefore, for men, it is obvious that the owner of an invention is honoured as an individual. This is not the case for women, who unconsciously project themselves not as an individual but as a member of a group, family, society, group of peers, etc., because they refer to a sort of a "double motherhood, biological and social maternity, with all that it induces as links with the others"[37]. This attitude of not being able to think as an individual and rewarded as such, could be explained, on the one hand, by the very recent access of women to what Kant calls "civil independence", because for a long-time woman have been considered dependent on the domestic order and in this space, it is the *pater familias* who is an individual citizen. His wife (as well as his children...) being minors, legally "incapable", that he manages in guardianship and represents in the public space. This practice of public space for women where they are recognized as citizens, and therefore as individuals, is still long in coming. On the other hand, it could be explained by what the philosopher Miranda Fricker calls "epistemic injustice", of which many women are victims, because they are not sufficiently prepared to present and defend their ideas. Epistemic injustice is defined as the exclusion and silence as well as the systematic distortion or under-representation of women's contributions[38], which is a way of denying them a frontline position. The other hypothesis could be given by the fact that women don't have the "culture" of promoting themselves. Indeed, research from Wharton and Harvard finds that when it comes to self-promotion, women systematically rate themselves lower than men do, even when their work is objectively better[39]. This non-recognition of themselves is defined by Pauline Clance as the impostor phenomenon, in which "individuals, especially successful women, believe themselves unworthy of promotion, recognition and reward, consider themselves impostors."[40] It is why, women rarely put themselves under the lights and don't even think about it. For example, WIPO (World Intellectual Property Organization) found that women inventors account for only 30.5% of all international applications filed under the WIPO Patent Cooperation Treaty. One of their directors, Olga Spasic, explains that even when women are granted patents, they are often not involved in the commercialization of their inventions and therefore do not get the spotlight[41]. This may explain the inability of women to think that they can be on the front line and have their own name recognized.

Concerning the most recognized chemical reactions, Friedel-Craft came first (78.1%) followed by Michael (55.7%) and Hofman (55.2%). The names of the other reactions are listed in Figure 2 with the percentage of recognition for each. Analysis of the responses by gender leads to the same conclusions as for the chemical engineering questions.

The students were then asked what percentage of inventors of a chemical process or chemical reaction they thought were men or women (Q3/13 - N = 594 - Fig 3). In chemical engineering, while 100% of the processes taught were invented by men, 3.5% of the students thought men were responsible for 0-20% of the processes, 0.7% for 20-40% of the processes, 5.4% for 40-60% of the processes, 30.4% for 60-80% of the processes, and 60.0% of the students thought men were responsible for 80-100% of the listed processes (total N = 425). In chemistry, while, once again, 100% of the list of reaction names were the names of men (mostly those who first discovered the reaction), 0.6% of the students thought men were the inventors of 0-20% of the reactions, 3.0% for 20-40% of the reactions, 5.9% for 40-60% of the reactions, 18.3% for 60-80% of the reactions, 72.2% for 80-100% of the reactions (total N = 169). For both panels, no specific difference was observed in the response between men and women. As an average of these results, students thought that 78.5% of the list of processes in chemical engineering and 79.8% of the list of chemical reactions were invented or discovered by men.

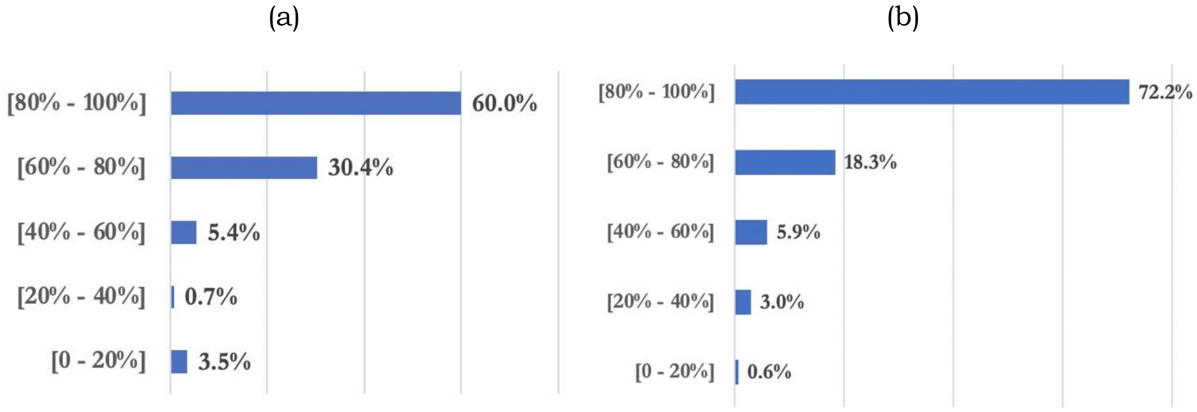



**Figure 3.** Third question of the survey - % of students thinking that the process/chemical reaction has a male inventor (Q3/13) for (a) chemical engineering (N = 425) and (b) chemistry (N = 169).

The fourth question focused on what students believed to be the best way to name a chemical process or a chemical reaction (Q4/13 – N = 594). Most of the students thought the best solution was to use the name of the company or of the person who patented the process or the reaction (39.8% - men 50.7%; women 32.0%), followed by a technological or operational reference to the process/reaction (26.6% - men 22.3%; women 30.1%), the name of the end product (18.2% - men 12.8%; women 21.8%). 15.4% of the students expressed no opinion on that question. Once again it is worth noting that men give more importance to the names of inventors than women, and women give more importance to the product than men.

In a list of twelve scientific discoveries, the students were asked to identify the ones they had heard of before (Q5 – N = 594), which of them they wanted to learn about (Q6 – N = 580), and which contributor they had already heard of. This list was made up only of a selection of important discoveries made by women in chemical engineering and chemistry. The results of these three questions are reported in Figure 4.

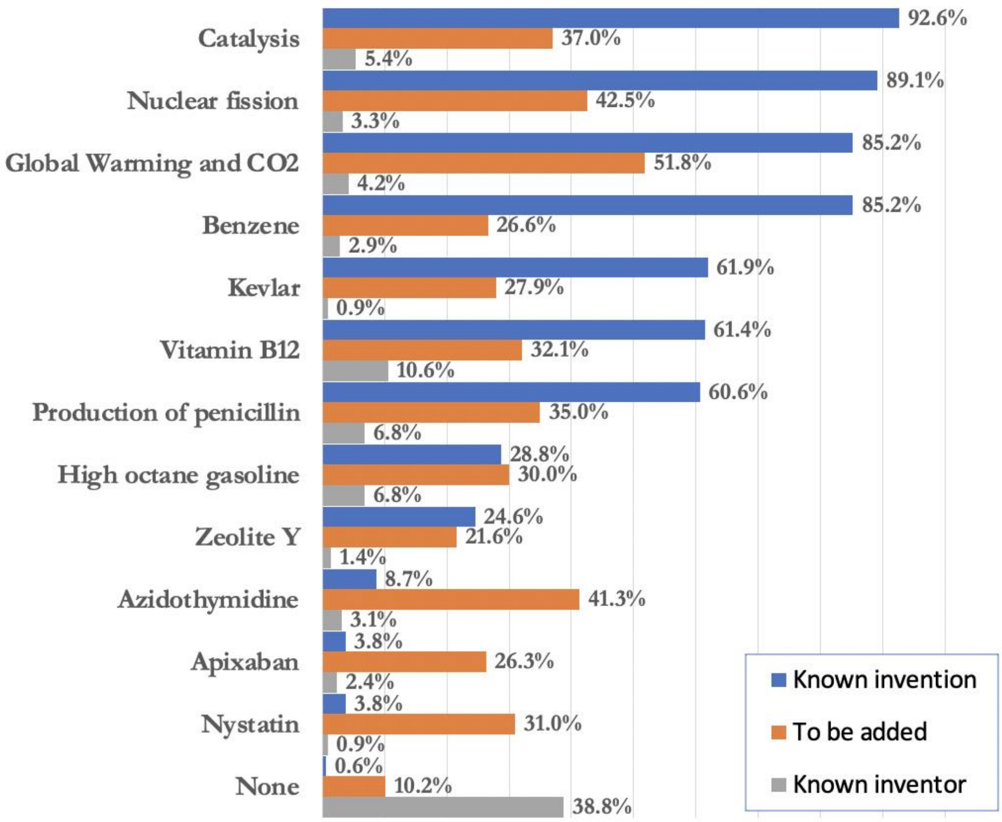



**Figure 4.** Fifth, sixth and seventh questions of the survey (Q5, Q6 and Q7/13) - percentage of students (blue) knowing a scientific discovery, (orange) wanting it to be added into the curriculum, and (gray) knowing the inventor of the discovery. N = 594 - 2020/2021.

Most of these inventions were well known to students, especially catalysis (92.6%), nuclear fission (89.1%), and the link between global warming and carbon dioxide (85.2%) while, surprisingly, the names of their inventors were familiar to only 5.4%, 3.3% and 4.2% of students, respectively. Most surprisingly, almost 39% of the student panel was unable to identify at least one of the twelve women inventors listed. The list also contained most of the Nobel Prize winners in the fields and, again surprisingly, students knew the names of these scientists poorly; Marie Slodowska-Curie was not included in this list as she is extremely famous in France (many universities, streets, etc. are named after her). The most famous women scientists were Irène Joliot-Curie (47.47%, Nobel Prize for Chemistry in 1935), Emmanuelle Charpentier (18.55%, Nobel Prize for Chemistry in 2020); both are French and present in the media in France. Then came, in order of recognition: Dorothy Hodgkin (6.02%, Nobel Prize for Chemistry in 1964), Jennifer Doudna (2.17%, Nobel Prize for Chemistry in 2020), Ada E. Yonath

(0.48%, Nobel Prize for Chemistry in 2009) and Donna Strickland (0.48%, Nobel Prize for Physics in 2018). Globally, one can conclude that the inventions of these women are generally known while their names are generally unknown. However, for better comparison, students should have been asked if they also knew some male Nobel Prize winners in the fields. The analysis of the results by gender gave very similar results between men and women, which suggests that the knowledge of scientists' names stems from learning in an academic setting and which, again, underlines the difficulty of disseminating the scientific culture of chemical engineering outside the academic framework.

In the next question, students were asked about the impact that such over-representation of male scientists in their studies (Q8/13 – N = 594) had on their feelings. A majority of students (62.5% - men 68%; women 52%) recognized that they had not paid attention to this over-representation, but the question had arisen for 22.8% of them. 15.9% of the students felt indifference to the over-representation of men while 11.8% felt disappointment (4% of men; 16% of women), 2.8% felt a drop in self-confidence (similar results for women and men), and 1.4% felt shame (similar results for women and men). It led 1.7% of the students to question their choice of training, and provoked anxiety and anger in some students (1.4% of the panel for each). It is worth noting that a majority of these students were women (i.e., 8% of the women students felt anger). 11.6% of the students expressed no opinion on this question. Once again differences between the feelings of men and women can be observed: more women paid attention to this issue, which caused stronger feelings of disappointment, while men seemed less concerned and impacted.

Interestingly, the choices of the student panel were dispersed when the members were asked if they thought that processes or chemical reactions taught in their courses put too much emphasis, through their names, on men (34.3% agreed and 32.3% disagreed – Q9/13 - Fig 5). This last response is in accordance with the fact that a large majority of students had never been aware of the over-representation of male scientists before taking this survey (Q8/13).

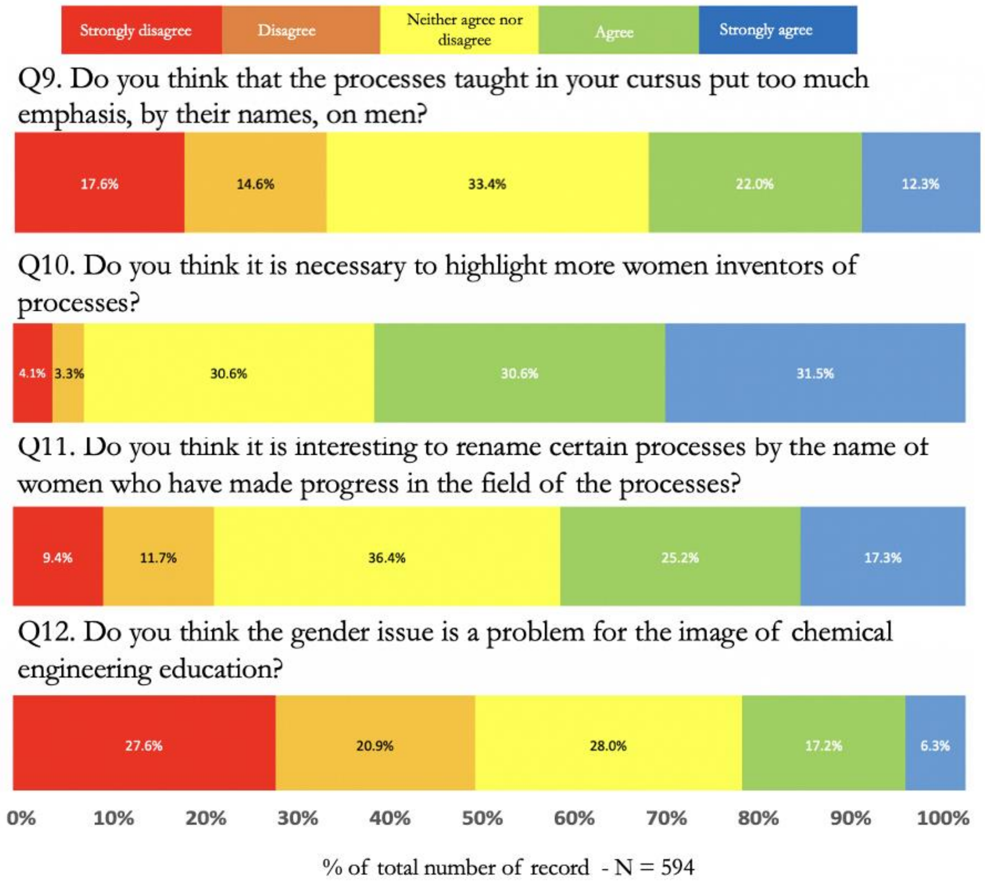



**Figure 5.** Ninth, tenth, eleventh and twelfth questions of the survey (Q9, Q10, Q11 and Q12/13). N = 594 - 2020/2021.

Nevertheless, a large majority of the students surveyed thought it necessary to highlight the work of more women scientists in their courses (62.0% in favour versus 7.4% against – Q10/13 - Fig 5). The analysis of the results by gender is shown in Figure 6. It can be seen that, while the majority of men seem to neither agree nor disagree on question Q10, women seem to want more women to be included in their curriculum.

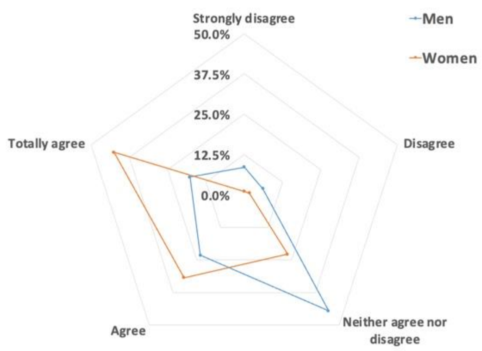



**Figure 6.** Necessity to highlight the work of more women scientists - Gender analysis of Q10 - N = 594 - 2020/2021.

A male/female balance could be achieved by renaming certain processes after women who made progress in the field of the process (42.5% in favour versus 21.1% against – Q11/13 - Fig 5). At the end of the day, only 23.5% of the student panel think the gender issue is a problem for the image of chemical engineering/chemistry education (versus 48.5% – Q12- Fig 5). Finally, a large majority (68.0% - Q13/13 – N = 594) think there is no need to emphasize aspects of the personal life of the inventors but, for 26.1%, gender should be mentioned, as should ethnicity (for 17.8%), sexual orientation (for 6.3%), gender identity (for 6.3%) or religion (for 3.1%). Some students (7.4%) used the free response section of this question to explain that, in their opinion, an invention or process should be included in the curriculum only if it is relevant to the course and/or important in the history of science.

## DISCUSSION

The results show that a large majority of students were not aware of the over-representation of male scientists before participating in this survey, which corroborates two ideas, namely that science is often linked to men and that misconceptions are persistent and perpetuated among both female and male students. The literature gives several explanations for this:

(1) Traditionally, when engineering schools were founded, they were reserved for men. It was around 1920 that the first women engineers appeared in the mixed engineering schools founded at that time. However, we cannot speak of true co-education, because the movement was very weak, and the cases of girls admitted were often unique. Moreover, some old and renowned schools remained closed to them; it was only in 1972, for example, that the École Polytechnique (Paris, France) admitted the first girls. The presence of women in engineering schools is therefore still relatively recent

(2) Two examples of prevailing stereotypes concerning gender and STEM persist as "boys are better at maths and science than girls" and "science and engineering careers are male fields"[42]. These stereotypes still implicitly maintain the beliefs that make male students choose the "hard" sciences and female students the

humanities[43]. Therefore, in a way, girls in engineering schools are still perceived as peculiarities, or even as a minority. As a result, the female dimension struggles to really become integrated in mentalities and therefore to initiate real changes.

(3) It is important to recall that, in France, engineering schools form part of prestigious schools of excellence, which led Pierre Bourdieu and Saint Martin to say that the universe of the “grandes écoles” is defined as a field which, in the prism of higher education, occupies a dominant position. Thus, through this dominant and very important position in the social space, these schools hold the field of power[44]. On the other hand, the domination of scientific fields over other fields, as well as the reproduction of scientific culture, which has become an important instrument of male domination in industrial society, has excluded women[45].

(4) The female/male distribution among teachers in the 5 universities surveyed is around 45%/55%. Nevertheless, we agree that, even though this is a form of representation, the students probably do not give the same credit to their teacher as to scientists who have made sufficiently important contributions to have their names mentioned in textbooks. On the other hand, we can assume that interactions with women engineers having high responsibilities – during internships, seminars or conferences, for example – have more impact. This has also been reported by recent research[46] that shows the positive impact produced when women chemical engineering students have the opportunity to interact with professional women chemical engineers (including the positive impact of this interaction on the student’s self-esteem and view of the profession).

(5) This situation can also be explained by what feminists call "the invisibility of women".[47] Because of a system of andocracy[48], this term was coined by feminist movements to reflect the gender discrimination against women and their exclusion from social, institutional and ideological systems. It speaks bluntly of a kind of 'negation' of women. Indeed, although they are concerned with objectivity, the exact, experimental or technological sciences are no less

impregnated with stereotypes on the differences and hierarchies between men and women. Too often, their generalisations are derived from a specific male perspective which is ignored as such[49]. The neutral reference claims to be universal, when it is not, since it occults women de facto.

(6) The last element of explanation relates to the content of textbooks and educational programmes at primary, lower and upper secondary level, which still convey many preconceived ideas and stereotypes. The Centre Hubertine Auclert[50] often warns against certain school contents that make us believe that, in our society, more than 90% of citizens are men, that great discoveries, art, philosophy and mathematics are fields reserved for men, that there are professions restricted to women and others restricted to men, and that women are above all "men's women" before being individuals in their own right. Studies on the content of textbooks for university students have shown that, beyond real, famous people, the gender of invented characters or authors of documents used in textbooks is overwhelmingly male. Female authors or celebrities are rarely or never mentioned. For example, women politicians and scientists are presented in the margins of chapters, through the few portraits of exceptional women. In mathematics textbooks, when women scientists are mentioned, several procedures tend to minimise their importance and their role in the history of science. For some women scientists, they are primarily associated with the work of their husbands, such as Marie Curie or Tatiana Ehrenfest. For others, there is no mention of their gender, as when the Agnesi curve or Sophie Germain's numbers are presented. Finally, in some cases, there is a pure and simple disappearance of certain women scientists or the absence of historical female figures in other fields, such as the first female programmers in history, or the mathematician Augusta Ada King. In fact, this way of concealing women also continues in the more advanced classes and, more particularly, in engineering schools.

There is a strong need to contextualize[51] science in History [52] and Society[53]; more story-telling historical approaches are needed to give the context of discoveries[54,55]. The dramatic absence of women in the names of chemical engineering processes or chemical reactions must be discussed with students to make them more aware of gender issues and the problems associated with diversity in general[6]. As the personification of names of chemical processes or chemical reactions is now almost impossible since discoveries are made by companies and patents are owned by dozens of authors, we can imagine that the increase in the number of women in science with time will not lead to a spontaneous rebalance in the future. It is the teachers' responsibility, if they find more relevant processes created by women than those that are currently studied in university/academic courses, to present them to the students. However, several strategies are possible:

(1) to remove names from all processes/reactions. This approach has been used recently by a French collective who created a fictitious French researcher (Camille Noûs - a unisex name[56]) to personify collective efforts in science, to protest against individualism, and to highlight the biases of an individual-centred evaluation of research. However, the campaign is ethically questionable as it may flout the basic principle of taking responsibility for an action as well as making authorship credit impossible. This strategy would reduce any over-representation, but educators would lose an opportunity to introduce history and geopolitics.

(2) to remove names but introduce scientific notions with their historical context in each course, so that students can learn the origins of these discoveries and their inventors, without any name being used in their everyday courses when dealing with these reactions or processes. In the case of a female inventor, this would provide an opportunity to explain the historical and general background that prevented women from freely presenting their work at conferences[67] or forced them to communicate on their results under a male name, as the French mathematician Marie-Sophie Germain did,[57] and to point out that the work of some women scientists was not even acknowledged but was attributed to their male scientific colleagues ("Matilda Effect"[28]). This strategy would aim to sensitize the students to the necessity of maintaining a good balance in diversity and equality, to highlight scientific history, which is part of the

education given by the university, and to respect the place of an inventor in the history of science, whatever their gender.

(3) to rename the processes/chemical reactions with women's names–a possible approach but one that is clearly not welcomed by students or the scientific communities[58,59].

(4) to increase the use and the application of inventions made by women/processes invented by women. As our panel's responses highlighted a desire to focus more on women[60] but not a desire to rewrite history by removing the names of men, this last option appears as the most effective and interesting one. Moreover, this strategy seems possible with respect to some oversights in chemical engineering and chemistry education.

More generally, it is important to integrate this reflection on gender equality in chemical engineering and chemistry education and to raise awareness of this dimension. This can be done through:

(5) Training teachers to raise their awareness of the choice of examples and references, which should tend towards parity. Some gender mainstreaming educators suggest setting up training modules for teachers on gender equality and promoting spaces for reflection on stereotypes as well as developing analyses of representations of women[61].

(6) Using what are known in economics as "role models". This involves having female students interact with female scientists with whom they can identify. These simple actions seem to be extremely effective. A large body of research shows that the presence of a female science teacher, for example, improves both the level of female students in science and their likelihood of pursuing science, as well as increasing male students' awareness of women in science (Canes & Rosen, 1995; Rothstein, 1999; Gardecki & Neumark, 1998; Bettinger & Long, 2005; Hoffman & Oreopoulos, 2009; Carrell et al., 2010)[62].

Some striking examples of important women inventors that could be used in teaching chemistry and chemical engineering are:

(i) Elizabeth Fulhame (fl. 1794), who, in 1794, wrote "An essay on combustion, with a view to a new art of dying and painting"[63]. This book was one of the first to describe catalysis and photoreduction[64–66]. Catalysis is now a multibillion-dollar sector worldwide (it processes over 80% of all manufactured products and accounts for around 30% of the gross domestic product in EU economies[67]) and pervades chemical engineering education[68–70]. Curiously, her narrative is seldom utilized in French classes (and, equally surprisingly, her name does not appear in the French edition of the online encyclopedia Wikipedia, but only in the English version). Fulhame described her book as possibly serving as "a beacon to future mariners", referring to women in the future of chemistry and science in general.

(ii) Stephanie Kwolek (1923-2014), who worked as a laboratory chemist at the DuPont Company, where she developed low-temperature processes for finding petroleum-based synthetic fibres. More specifically, she determined the conditions needed to produce Nomex, a flame-resistant fibre, in 1961, and Kevlar, a high-strength fibre, in 1971.[71,72] Her findings were of broad scientific and industrial interest and are now used for polymer synthesis and for teaching surface investigation. [73]

(iii) Rachel Brown (1898-1980), who worked in the 1940s to characterize pneumococci in order to treat pneumonia[74]. Brown collaborated with scientist Elizabeth Lee Hazen, and they created nystatin, the first antifungal drug that was both safe and successful in treating human ailments.[75,76] They later discovered two other antibiotics, phalmycin and capacidin. [74]

(iv) Edith Flanigen (1929 -), who worked at Union Carbide on the synthesis of emeralds and, later, zeolites for molecular sieves. [77] She created zeolite Y, a molecular filter that could purify petroleum, in 1956. The catalyst zeolite Y increases the quantity of gasoline fractionated from petroleum, [78] making petroleum refining safer and more productive.

(v) Physicist Lise Meitner (1878-1968), who discovered a new element, protactinium, alongside scientist Otto Hahn in 1918. They were the first to describe the fission process in 1938. Despite her several distinctions, Meitner did not receive the Nobel Prize for Physics, which was given to Otto Hahn[79] for the discovery of nuclear fission. She has been nominated for the Nobel Prize 48 times in total[80,81]. In 1923, she wrote an essay about non-radiative transition that was unrelated to her work with Otto Hahn. The name Meitnerium was given to element 109 in 1997.

(vi) Kathleen Lonsdale (1903-1971), who was a crystallographer.[82] In 1929, she proved that the benzene ring was flat by using X-ray diffraction methods to elucidate the structure of hexamethylbenzene. Benzene is used mainly as an intermediate to make other chemicals,[83] above all ethylbenzene, cumene, cyclohexane, nitrobenzene, and alkylbenzene. More than half of the global benzene production is processed into ethylbenzene, a precursor of styrene, which is used to make polymers and plastics like polystyrene.

(vii) Dorothy Hodgkin (1910-1994), who was awarded the Nobel Prize in chemistry in 1964 for advancing the technique of X-ray crystallography to determine the structure of biomolecules. Among her most influential discoveries are the confirmation of the structure of penicillin, the structure of vitamin B12 and the structure of insulin.

(viii) Margaret Hutchinson Rousseau (1910-2000), an American chemical engineer who designed the first production plant for commercial penicillin. In 1927, she was the first woman to obtain a PhD in chemical engineering from the Massachusetts Institute of Technology (MIT) and, in 1945, she became the first female member of the American Institute of Chemical Engineers[84] (AIChE).

(ix) Eunice Newton Foote (1819 – 1888), who was an American scientist, inventor, and women's rights activist. She was the first scientist to experiment with the warming impact of sunshine on various gases and, in 1856, she proposed that variations in the quantity of carbon dioxide in the atmosphere would alter the temperature of the atmosphere. [85] Because she was a woman, she was not allowed to present her work at conferences, but she did manage to have it published. Her name may have been added to the pantheon of early climate scientists as a result of her publication[86], but she was swiftly forgotten and drifted into obscurity. Her name came to light again in 2010, and she is now being recognized for her work. Some consider her as the "Rosa Parks of Science".[87]

This last example is a striking reminder of how history has forgotten important discoveries made by women, a phenomenon that still seems to be occurring nowadays (pages on female scientists regularly disappear from Wikipedia[88] and the rejection rate of new pages on female scientists is double that for male scientists). To re-establish some balance on this point, we suggest that educators use the stories and the names of these scientists in their courses: (a) the Fulhame process for some important catalytic processes, (b) the Kwolek process for the Kevlar production process, (c) the Fuller Brown- Lee Hazen process for antifungal antibiotic production (d) the Flanigen process for petroleum/zeolite catalysed production, (e) the Lonsdale process for the production of benzene or derivatives, and (f) the Newton Foote process for any $CO_2$ capturing processes. Moreover, these scientists could also be used in specific courses: (i) for example, the discovery of nystatin by Rachel Brown and Elizabeth Lee Hazen or the synthesis of zeolites by Edith Flanagan could be examples used in the Separations course for chemical engineering, ii) the work of Dorothy Hodgkin and Kathleen Lonsdale as crystallographers could be incorporated into the chemistry curriculum in an analytical methods course, (iii) for the Reaction Engineering course, the work of Fulhame and Kwolek could be covered, (iv) Frances Arnold, a recent Nobel Prize winner, is a chemical engineer and whose work in creating new enzymes could easily be incorporated into a reaction engineering course and, finally (v) the works of Margaret Hutchinson Rousseau should be discussed in Process Design type courses.

These named scientists and processes will rebalance the female/male representation to an acceptable 20-30% of illustrated named processes or discovery, which is more in agreement with the proportion of women working in chemical engineering and chemistry.

Besides being used to rebalance the over-representation of men, the approach proposed could be more largely used to propose diversity in chemical and chemical engineering courses. For example, concerning another important aspect of DEIR dealing with the balance of ethnicity, the work of Norbert Rillieux could be used. He invented the multiple-effect evaporator in 1854,[89] which harnessed steam energy from boiling sugarcane juice, thus greatly reducing refining costs. It is a good example that could illustrate the equality issues, as Rillieux's patent was initially declined because it was believed he was enslaved.

## CONCLUSION

The purpose of this study was to provide a unique quantitative picture of how our universities have approached the place of women in historical and classical chemical engineering and chemistry classes, using a survey concerning possible practices and challenges, and in-depth discussions on the results. A total over-representation of male scientists has been observed in the examples used to illustrate our historical chemical engineering processes and chemistry reactions. The absence of women in the illustration of the curriculum is due to the small number of women working in science before 1940 but, after analysing some important discoveries by women in the field and by underlining the difficulties they had to face when attempting to publish or communicate about their work, we could speculate that male over-representation in chemical engineering could, as in chemistry[31], reflect and perpetuate unconscious gender bias in science. In order to evaluate the impact of such bias on the feelings and thinking of students, a survey was designed, and filled out by more than 600 students (more than 400 in chemical engineering and more than 200 in chemistry) in seven different universities in France. Many students did not even know where the names of the processes that they studied came from (company, location, scientist's name, etc.) and the vast majority did not realize that the scientists mentioned were all men. Indeed, 90% of the student panel were unable to identify a woman in the chemical engineering field, and the remaining 10% could only cite one or two (the most recent and mediatized). However, this also reveals that, nowadays, particular attention is paid when the work of a female scientist stands out, and this is encouraging. This revelation led to much questioning from the students (22% of the panel), although responses also showed their disappointment (10%) or indifference (15%). An overwhelming majority wanted more women to be present in examples of applications (60%) but without renaming the processes already named after male scientists (60%). A majority of students thought that the gender of the scientists used as examples in classes was not a problem for the discipline and that history must be respected. Nevertheless, a historical analysis of important discoveries in chemical engineering revealed that key parts of history should be rehabilitated and illustrated in classes, and interest in these discoveries seems high in our student panel (between 20 and 50% of interest). A list of highly interesting applications and too-easily-forgotten discoveries has been provided as a striking example of the presence of women in science despite all the difficulties they faced to be remembered in history. We encourage educators all around the world to promote these scientists by naming their inventions, naming their processes, and telling their unique stories to engage both female and male students equally and inclusively. It is the duty of educators to question themselves about what learning should be, how to make a place for everyone with diversity, equality, inclusion and respect, and how to rebalance what history has forgotten in order to empower women to take their rightful place in chemical engineering classes.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