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Research Article

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Analyzing the existing programs on promoting women scientists in chemistry

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Abstract: Gender imbalance in science has been well documented. Possible explanations include a lack of systematic strategies or policies to support women in science in general and chemistry in particular. This article aims to analyze selected programs that advocate gender equity and inclusion in chemistry. Forty-eight initiatives were selected via several steps of screening. Following a pilot study using systematic review as a research method, the named initiatives were analyzed considering their strategies, goals, and impact. The findings reveal that acknowledging women scientists and providing funding to enable and sustain networking (such as through conferences) are crucial for women scientists to become visible and recognized in academia. In this paper, we offer recommendations for other entities who would like to develop initiatives to encourage suitable environments for gender equity.

Keywords: gender gap; women in STEM; good practices; women scientists; science policy; chemistry

1 Introduction

The internationally acknowledged gender gap in science continues to be a concern to science educators (Makarova et al., 2019; Morgenroth & Ryan, 2018), as transforming our world and promoting inclusion continues to be an intellectual, social, scientific, and political challenge (Vargas & Soares, 2019). About 49.7 % of the world's human population are female, and they carry undeniable potential to participate in social, scientific, and economic development, women continue to be significantly underrepresented in almost every high-profile human activity, including science (The World Bank, 2022). Even in countries where women have been widely integrated into these high-profile human activities, women frequently occupy only supporting positions or are underpaid compared to the men who perform the same role (UNESCO Institute for Statistics, 2023).

Currently, in science, approximately 30 % of researchers worldwide are women (Conte et al., 2021; Gray, 2016). This is due to longstanding gender bias and stereotypes that discourage women from science-related fields, in particular Science, Technology, Engineering, and Mathematics (STEM) research. Furthermore, women are also underrepresented in the field of chemistry (see Figure 1). Just to give an example from the Nobel Prize ceremonies, only 61 out of the 959 Nobel prize recipients have been women, and only 8 out of 189 individuals who have

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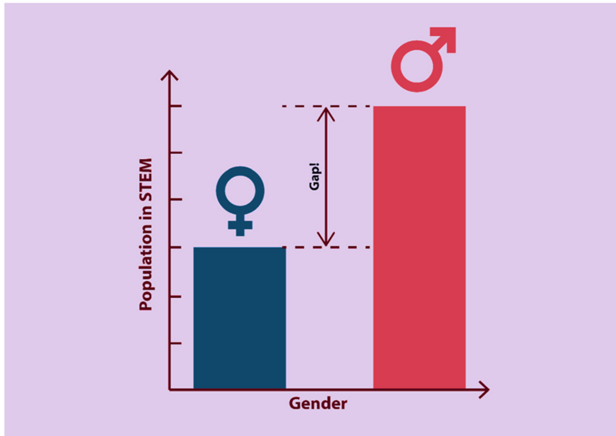

Figure 1: A pictorial representation of the gender gap in STEM.

received the Nobel Prize in Chemistry since 1901 were female despite their outstanding breakthroughs (Ross et al., 2022; The Nobel Prize, 2022). However, it is known that women have made significant contributions to STEM despite the lack of recognition and awards. This lack was presumably due to gender bias in the past, where women did not have equitable access to higher education (Stockard et al., 2018). For instance, British chemist Rosalind E. Franklin (1920–1958), who was known for her work in X-ray diffraction, made monumental discoveries but was not recognized with awards.

This paper investigates initiatives to encourage women to participate in the field of chemistry. The authors used a systematic review of international projects to find and categorize existing programs and initiatives by searching public websites of chemistry societies, universities, and other relevant organizations. We then analyzed these initiatives to see what types of activities are being used, what goals the initiatives have, and what impact they might have. The ultimate goal is to create a database of these programs that can be easily accessed and expanded upon in the future, to share best practices and encourage broader participation in STEM fields.

2 Gender gap in chemistry and good practices

The gender gap in STEM is not a new topic, but progress has been limited over the past decades. While this paper does not explicitly address gap-gazing, a phenomenon characterized by Gutiérrez (2008) in mathematics education, it aims to move beyond simply identifying the gender gap in chemistry. It focuses on analyzing existing initiatives to understand how the gap is being addressed. For instance, the percentage of women in STEM fields in academia has recently decreased (Grunert & Bodner, 2011), and the numbers of publications are still smaller than those for men. In chemistry, the situation is similar (Chiu & Cesa, 2020).

While it is not a secret that the gender gap still exists, it is changing slowly (Ross et al., 2022). There are programs are designed to encourage women to study science. Research has revealed that women who receive positive feedback and inspiration are motivated to study and conduct chemistry research. Programs from various organizations that provide professional development workshops on academia, awards, or policies on gender equity fulfill this need (Chiu & Cesa, 2020; Miller-Friedmann et al., 2018; United Nations, 1979). Even so, formal mechanisms for collaboration between scientists and policy-makers are elusive and often lacking, preventing an effective dialogue and evidence-informed actions, as reported by John et al. (2023). However, there are numerous examples of programs and initiatives to recognize women's achievements.

To determine the most effective practices for supporting women scientists in their careers or studies, it is necessary to identify the challenges women encounter. To address these challenges and identify supportive practices with demonstrable potential in the field of chemistry, the authors of this article have developed several criteria to assess these initiatives.

3 Research questions

As Spini et al. (2021) argued, even though gender discrimination and harassment have been observed in various scientific fields, there is still no overall practice to raise awareness amongst both women and men to reduce or avoid overall gender-based discrimination. However, over the last several decades, scholars from all over the world have offered a variety of initiatives and programs to close the gender gap in chemistry. In this report, initiatives and programs are reviewed.

In this paper, the following research questions are used as guidelines:
- RQ1: What is the distribution of types of practices?
- RQ2: What is the distribution of goals of the practices?
- RQ3: What is the distribution of potential impacts of the practices?

4 Methods

To answer these research questions, a pilot study was carried out using a qualitative systematic review as a research method (Grant & Booth, 2009). Compared with a traditional systematic review, the present study is not based on publications and papers, but rather on Web homepages accessible on the internet, that describe the programs and initiatives. The method described in this paper, which included the compilation and review of a database described below, is believed to be a useful contribution to the field. The goal is to present a database that is accessible and expandable so that it can capture more initiatives in the future.

4.1 Research procedures

To start, the first step of this pilot study was to apply a systematic review of the evaluation of pre-existing databases on STEM (European Institute for Gender Equality, 2023), and other initiatives. Here, the analysis was done with a focus on chemistry. Furthermore, the geographical region and sources of the initiatives were noted. In parallel to this, a comparison was conducted with the lists on a related Plotina webpage (Plotina, 2023), as well as WorldWideLearn (2021). The Plotina platform is a commissioned project by the European Unions that is not solely focused on STEM. WorldWideLearn includes a disclaimer that it does not provide a comprehensive list of all schools that offer a particular program of study, and it receives compensation for many of the featured schools on the websites. Therefore, to minimize biases in our search we did not use them as a starting point.

In the second step, in addition to identifying homepages in English, search engines (e.g., Google.com, Google.fr, Google.es) were used. For websites in certain different languages (Spanish, French, German, Chinese, and Korean) Google Translate was used. These non-English languages were selected because the authors had sufficient knowledge that the translated texts could be verified. The search Syntax was “Woman” OR “Girls” OR “Girls in Chemistry” OR “Women in Chemistry” OR “Women and Girls in Chemistry”.

In the third step, 123 initiatives from chemical societies worldwide were found and evaluated. There are hundreds of chemical societies across the world, with many of them being country or region-specific, and others that are focused on specific fields or sub-disciplines within chemistry. Some of these chemical societies did not have a webpage and therefore they were excluded. Chemical society homepages (e.g., Algerian Chemical Society (SAC), Jordanian Chemical Society, Pancyprian Union of Chemists, Chinese Chemical Society, Caribbean Academy of Sciences (CAS), etc.), homepages were evaluated and searched for initiatives of interest. In the end, 21 were found to fit our criteria.

The same procedure was adopted with the homepages of 111 universities, including English-, German-, French-, and Spanish-speaking universities. These languages were selected because we had help from people who could write and understand these languages. From this list of 111, we could only find 11 that contained a specific webpage detailing an initiative. This means that even if the search terms and keywords identified a university’s website, but there was no webpage describing any initiatives, they were excluded. For instance, a positive search result could mean that there was a news report of "how can you inspire women to enroll for a course of studies in the STEM area" (WorldWideLearn, 2021), but what appeared was an anecdotal report of a student sharing her experiences. This was excluded in our database as it did not fit into our criteria of a collective initiative supported by a group or organization.

Next, online search results for organizations other than chemical societies or universities yielded other webpage-documented initiatives. These organizations were STEM-focused or chemistry-focused. An example of a STEM-focused but not specifically chemistry-focused organization is the American Association for the Advancement of Science (Marion Milligan Mason Award: Women in the Chemical Sciences, 2023). The rest include chemistry program-based webpages and chemistry journal-based initiatives. The former includes Women in Supramolecular Chemistry (2023), Women in Catalysis (The Young European Catalysis Network, 2024), and the latter includes publications from Royal Society of Chemistry, the American Chemical Society, and others.

Based on this approach, our list contained 68 initiatives. Next, exclusion criteria were applied to further filter the results before our analysis.

Exclusions were done using the following criteria:

- The homepage of the initiative does not exist anymore.
- The initiative was offered only once.
- The homepage was in a language which was not understandable to the authors.
- The focus was not on chemistry but STEM in general.
- The focus was not clear.

Finally, the analysis was carried out on a total of 48 initiatives (an Excel file is appended on the "progress" section at the IUPAC website (2024)). Initiatives were entered into the database list as follows: Name of the Initiative, Web Link, Year or Origin, Participating Country/ies, Funding Source, Discipline/s, Target Level.

4.2 Development of the evaluation rubric

For the analysis of the data, evaluation rubrics were developed. Starting from the developed database, a deductive-inductive sorting of the categories was done to develop a coding scheme. Deductive-inductive sorting is a strategy that combines existing approaches with themes emerging from the data. The development employed a thematic coding approach to identify recurring patterns and concepts within the database. To ensure inter-coder reliability, for each included initiative, at least two coders independently coded the content line-by-line, assigning preliminary codes that captured the essence of the content. These initial codes were then reviewed and refined through an iterative process, with codes being merged, split, or discarded to ensure a consistent and theoretically relevant coding scheme. Throughout this process, constant comparison techniques were used, where data segments with similar codes were compared to identify emerging themes and ensure the codes accurately reflected the data's richness.

To further enhance the rigor of the coding process, after the two independent coders finished, the coding for each link was validated by two of the manuscript's authors. In cases of coder discrepancies, one of the authors would step in to resolve the conflict. Similarly, if conflicts arose between the two validating authors, the last author of the manuscript would help to achieve consensus. This multi-step coding process with conflict resolution procedures ensured the trustworthiness and credibility of the thematic analysis.

Following the research question RQ1, the main categories are derived from (i) activities and strategies for closing the gender gap, (ii) goals of the initiative, and (iii) potential impact of the initiative. For each of the three main categories, subcategories are developed from the information from the database. This is further expanded in the next sections. For each research question (RQ), coding rubrics were generated based on the associated criteria to evaluate the initiatives in the database. In RQ1, which analyzed the activities and strategies for closing the gender gap, there are 8 coding rubrics (Table 1). As a general principle, the criteria must involve women in the coding rubrics, for example in books and manuscript authorships and/or editorships (Indicator 1.1). Activities such as conferences, symposia, and workshops that have themes on girls and women are also included (Indicator 1.4). It is vital to have mentoring programs that illustrate evidence that women were the majority of the

Table 1: Coding scheme for the categories derived from the research questions (RQ1).

Research question	Code indicators	Criteria	Exemplar of references
1. What categories emerge when we survey the practices employed by programs that support and promote women and chemistry?	1.1 Books and manuscripts	Names of women on books and/or manuscripts written and edited by women	ChemCatChem Successful Women in Chemistry
	1.2 Women's journal	Journals that publish women authors (e.g., special issues or WISC)	Women in Science (Frontier in Chemistry) Women in Supramolecular Chemistry
	1.3 Studies about women in chemistry	The focus is on both women and chemistry in tandem	Breaking the Barrier Development of entrepreneurial skills (articles)
	1.4 Conferences, symposia, workshops	Conferences, symposia, and workshops with themes about women and girls	Basic Analytical Chemistry Course for Women Caltech Women in Chemistry Chemistry le Chéile Erlangen Symposium Empowering Women In Organic Chemistry – Europe EWOC Conference Rosalind Franklin Forum Woman in Chemistry Symposium (OPCW) Women in Chemistry Symposium (UTwente) Women of Distinction in Material Science (Darmstadt) Women in Supramolecular Chemistry Women in Chemistry Initiative Virtual Women's IQCC Forum
	1.5 Mentoring program	Mentoring programs have mentors providing ongoing guidance to mentees	Caltech Women in Chemistry Celebrating Women in Chemistry Conference Sri Lankan Women Chemists Breakfast Women in Chemistry (Nottingham) Women in Chemistry Initiative
	1.6 Chemistry courses for women	Courses or classes exclusive to women as participants	Chemisch Dispuut Leiden Erlangen Symposium Girl Scouts Chemistry Workshop
	1.7 Global women's network	Documented results of events that celebrates the community and network of women in the world	Empowering Women In Chemistry: A Global Networking Event Global Women's Breakfast (https://iupac.org/gwb/) Sri Lankan Women Chemists Breakfast
	1.8 Awards	Prizes or awards for women/achievements as well as for enhancing young women's careers in science	ACS Award for Encouraging Women into Careers in the Chemical Sciences ACS Women Chemists Committee Award CCS celebrates outstanding women in chemistry Dr. Margaret Faul Women in Chemistry Award Eye-Sense Female Chemist Award IUPAC Distinguished women in Chemistry or Chemical Engineering Marion Milligan Mason Award: Women in the Chemical Sciences SNIC-AsCA2019 Distinguished Woman Chemist Award

Table 2: Coding scheme for the categories derived from the research questions (RQ2).

Research question	Code indicators	Criteria	Exemplar of references
2. What goals emerge when we survey the practices employed by programs that support and promote women and chemistry?	2.1 Perceptions, attitudes, behaviors, social norms and stereotypes	Changing perceptions, attitudes, behaviors, social norms and stereotypes via surveys or questionnaires, etc. Anecdotal evidence is excluded	Breaking the Barrier ChemCatChem Chemistry le Chéile Successful Women in Chemistry Women In Supramolecular Chemistry
	2.2 Engagement	Engage girls & young women in STEM primary & secondary education, as well as in technical & vocational education and training	Swiss Women in Chemistry (SWC) USask Women in Chemistry Women in Science (Frontier in Chemistry) Women in Supramolecular Chemistry
	2.3 Retention	Access to and retention of women in STEM higher education is clearly articulated in part of the aim and/or vision	Breaking the Barrier Successful Women in Chemistry
	2.4 Career progression	Promotion of gender quality in career progression is encoded clearly in the aim and objective	Basic Analytical Chemistry Course for Women Caltech Women in Chemistry Woman in Chemistry (Nigeria) Woman in Chemistry Symposium (OPCW)
	2.5 Promote the gender dimension in research content, practice, and agendas	These programs are directed towards research and practice	Basic Analytical Chemistry Course for Women Celebrating Women in Chemistry Conference Rosalind Franklin Forum Swiss Women in Chemistry (SWC) Women in Chemistry Initiative
	2.6 STEM-related policymaking	Policy-related documents	Women in Chemistry Symposium (UTwente) Women of Distinction in Material Science (Darmstadt) Virtual Women's IQCC Forum
	2.7 Entrepreneurship and innovation	Promote gender equality in science and technology-based endeavors. Mentions of enterprises, start-ups, or companies	Erlangen Symposium Empowering Women In Organic Chemistry – Europe EWOC Conference Woman in Chemistry (Nigeria) Women In Supramolecular Chemistry

participants (Indicator 1.5). For the metric on "chemistry courses for women", the initiatives were analyzed only on courses and classes exclusively for women as participants (Indicator 1.6).

For RQ2, which examines the goals of the initiatives, there are 7 coding rubrics (Table 2). For the metric, "Perceptions, attitudes, behaviors, social norms, and stereotypes", there should be data such as survey results to substantiate claims of such changes via surveys or questionnaires (Indicator 2.1). Anecdotal evidence is not included. For the metric, "Engagement", the involvement of younger women should be mentioned (Indicator 2.2). Next, an initiative would fulfill the metric, "Retention," if promoting access to and retention of women in STEM higher education at all levels was stated as part of their aims or visions (Indicator 2.3). If an initiative promotes gender equality in science or technology-based endeavors or mentions enterprises, start-ups, or companies, it would have met the metric "Entrepreneurship and innovation" (Indicator 2.7).

For RQ3, which identifies the potential impacts of the programs for reducing the gender gap, 8 coding rubrics were generated. An initiative that shows evidence of successive occurrence of the same event or repeated occurrences every alternate 2 or 3 years, or the presence of regular updates on social, would be considered as having "Continuity" (Indicator 3.1). Evidence of anecdotes about role models or mentors enabling more students to turn to chemistry is noted (Indicator 3.2). Further, evidence of support by various institutions, for example, universities, corporations, or organizations, institution is documented (Indicator 3.4), as well as the presence of policies that are in place to support women in STEM (Indicator 3.5).

5 Results

In the following section, the results of our work are presented according to the three research questions and main categories.

5.1 RQ1: Activities and strategies for closing the gender gap

Table 1 summarizes the results for RQ1, showcasing various activities and strategies designed to close the gender gap in chemistry. Many projects can be cross-listed as they fulfill multiple characteristics. Notably, under indicator 1.4 (n = 26), numerous conferences, symposia, and workshops specifically address the needs and achievements of women in chemistry. Examples include the Woman in Chemistry Symposium by OPCW (#39 in the spreadsheet), Caltech Women in Chemistry (#7), and the Rosalind Franklin Forum for Female Scientists (#31). These events provide platforms for women to network, share knowledge, and inspire future generations.

One indicator stands out: awarding prizes or recognition for women's achievements and career advancement (indicator 1.8, n = 9). The American Chemical Society (ACS) exemplifies this through the ACS Award for Encouraging Women into Careers in the Chemical Sciences (#1), the ACS National Awards for Women Chemists (#2), and the ACS Women Chemists Committee Award (#3). Notably, awards specifically for women are the second most common practice identified. These awards often recognize outstanding contributions by female researchers while providing financial support for their work. For instance, the Marion Milligan Mason Award: Women in Chemical Sciences (#30) by the American Association for the Advancement of Science (AAAS, 2023) grants promising young women researchers $55,000 every other year to kick-start their careers.

Another noteworthy indicator is the IUPAC's Global Women's Breakfast (indicator 1.7, n = 3). Launched in 2011 and relaunched in 2019, IUPAC hosted the Global Women's Breakfast (GWB) events (Choo et al., 2024; Kerton, 2022), which have taken place annually for the past six years, with over 1,500 events held in 100 countries. All the individual GWB events held across the globe are categorized under this indicator. Notably, the 2023 IUPAC Global Women's Breakfast was recognized as a flagship event for the UN's International Year of Basic Sciences for Sustainable Development (IYBSSD) (Brett, 2022).

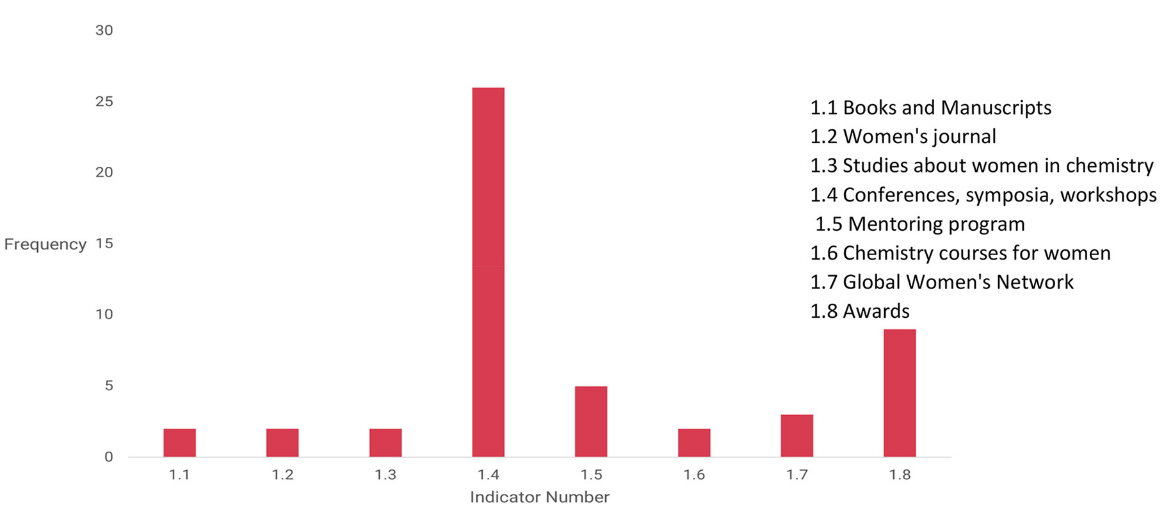

Figure 2: The frequency of initiatives that were coded across the RQ1 indicators.

Finally, under indicator 1.2 (n = 2): "Women's journals," two publications were identified that provide a platform for female scientists: Frontiers in Chemistry (#45) and Women in Science: Chemistry (#46). The frequency of initiatives coded across RQ1 indicators is visualized in Figure 2.

5.2 RQ2: Goals of the initiative

Table 2 summarizes the main goals identified for initiatives aimed at achieving gender equality in chemistry. The top five indicators are 2.5 (n = 18), 2.2 (n = 17), 2.4 (n = 17), 2.1 (n = 15), 2.7 (n = 13), shown in Figure 2. Indicator 2.5 specifically targets research. Initiatives like the Rosalind Franklin Forum (#31) and the Women in Chemistry Initiative (#48) promote the inclusion of gender perspectives in research content, practices, and agendas.

Indicator 2.2 describes initiatives that engage girls and young women in science, technology, engineering, and mathematics (STEM) fields. It targets primary and secondary education, as well as technical and vocational training. For instance, by arranging for girls in small groups to visit various workshop stations where they attain hands-on experiments, girls' interest in science is ignited. Examples include programs like Women in Science (Frontier in Chemistry) and Women in Supramolecular Chemistry. It is important to note that many projects address multiple goals. For example, "Women in Chemistry (Nigeria)" (#41) established in 2015 fosters networking, mentoring, and collaboration among female chemists (https://chemsociety.org.ng/). This initiative aligns with both indicator 2.4 (career progression) and indicator 2.7 (Entrepreneurship and Innovation). Next, indicator 2.1 "Perceptions, attitudes, behaviors, social norms and stereotypes," is about making changes via surveys or questionnaires, with ChemCatChem and Successful Women in Chemistry as examples. We posit that surveys and questionnaires are good practices as they not only illuminate existing biases and track progress towards gender equality, but also raise awareness through participation and provide data-driven evidence to advocate for change, ultimately chipping away at stereotypes and social norms that hinder a more equitable society.

While not as prevalent, some initiatives address gender in STEM-related policymaking (Indicator 2.6, "STEM-related policymaking"). This goal is understandably ambitious and political, potentially explaining the lower number of projects. Examples include the Women in Chemistry Symposium (UTwente #44), Women of Distinction in Material Science (Darmstadt #47), the Virtual Women's IQCC Forum (#38), and Chemistry le Chéile (#13). The data is nonetheless encouraging, highlighting numerous projects and activities working to improve women's standing in both general science and academia. The frequency of these initiatives coded across the RQ2 indicators is visualized in Figure 3.

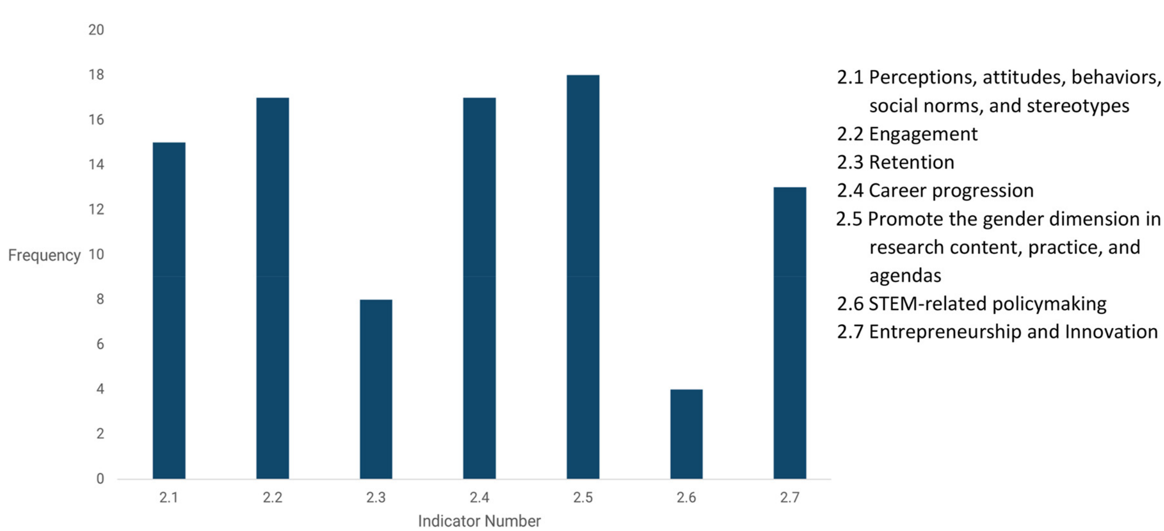

Figure 3: The frequency of initiatives that were coded across the RQ2 indicators.

Table 3: Coding scheme for the categories derived from the research questions (RQ3).

Research question	Code indicators	Criteria	Exemplar of references
1. What potential impacts emerge when we survey the practices employed by programs that support and promote women and chemistry?	3.1 Continuity	Evidence of successive occurrence of the same event or repeated occurrences every alternate 2 or 3 years, or presence of regular updates on social	ACS Award for Encouraging Women into Careers in the Chemical Sciences ACS National Awards for Women Chemists ACS Women Chemists Committee Award CCS celebrates outstanding women in chemistry Chemical Society Located in Taipei Distinguished Women in Chemistry or Chemical Engineering EWOC Conference Girl Scouts Chemistry Workshop
	3.2 Role model/mentor	Evidence of anecdotes about the role model or mentors enabling more students to turn to chemistry	ACS Award for Encouraging Women into Careers in the Chemical Sciences Caltech Women in Chemistry
	3.3 Description of the value of project	Indication of funding or financial support	ACS Women Chemists Committee Award Girl Scouts Chemistry Workshop Rosalind Franklin Forum
	3.4 Institutional support	Evidence of support by institutions (e.g., universities, corporations, or organizations)	ACS National Awards for Women Chemists ACS Women Chemists Committee Award CCS celebrates outstanding women in chemistry Celebrating Women in Chemistry conference Chemical Society Located in Taipei Eye-Sense Female Chemist Award Rosalind Franklin Forum SNIC-AsCA2019 Distinguished Woman Chemist Award Woman in Chemistry Symposium (OPCW) Women in Chemistry Initiative
	3.5 Policies	There are policies in place to support women in STEM	Chemical Society Located in Taipei Distinguished women in Chemistry or Chemical Engineering Eye-Sense Female Chemist Award
	3.6 Community	There is a potential to reach a wider community	ACS Award for Encouraging Women into Careers in the Chemical Sciences ACS Women Chemists Committee Award Marion Milligan Mason Award: Women in the Chemical Sciences
	3.7 Scale	The impact/influence should be either national, regional, global	CCS celebrates outstanding women in chemistry Celebrating Women in Chemistry Conference Empowering Women in Organic Chemistry – Europe Girl Scouts Chemistry Workshop Global Women's Breakfast
	3.8 Women and men	There are participations from both women and men in the initiative	Chemisch Dispuut Leiden Erlangen Symposium Girl Scouts Chemistry Workshop

5.3 RQ3: Potential impact of the initiative

Table 3 lists the coding rubrics that were used in measuring the potential impacts of the initiatives adopted by various organizations and the fulfillment of coding rubrics for RQ3. Two of the indicators 3.1 (continuity, $n = 23$) and 3.4 (institutional support, $n = 31$) are particularly high, shown in Figure 3. For the indicator 3.1 "continuity" criteria, there are 23 organizations out of the 48 that fulfil either because they hold the events annually, or because their social media has been updated regularly. Demonstrating continuity is crucial for initiatives aiming to achieve lasting impact. Large organizations, like the organizers of the IUPAC Global Women's Breakfast (IUPAC GWB), showcase this commitment through frequent events. Their biennial networking event exemplifies this consistent approach. Similarly, the ACS Award for Encouraging Women into Careers in the Chemical Sciences (#1) is another program offered year after year.

Indicator 3.4 is "institutional support". Besides financial support, it is also beneficial for an initiative to be supported by established institutions. 31 of the named initiatives are included in this indicator. Universities and institutes of higher education appear to be among the most common backers. For instance, the "Women in Chemistry Initiative" is supported by the University of California, Berkeley (#48), and the "Celebrating Women in Chemistry conference" is supported by the University of Nottingham in the UK (#9). Several initiatives are supported by large organizations; for example, the "Empowering Women In Chemistry: A Global Networking Event", which was a theme of a recent Global Women's Breakfast event, is supported by IUPAC, while "ACS Award for Encouraging Women into Careers in the Chemical Sciences" is supported by The Camille and Henry Dreyfus Foundation. As reported in Miller-Friedmann et al. (2018), 15 providing particularly targeted support, such as assistance in coping with financial instability, help academic women in chemistry succeed.

For a program to meet indicator 3.2, "Role model/mentor", the key criterion is positive evidence of sharing of anecdotes that role models or mentors have enabled more women to study chemistry. There are only five that fulfill this criterion, including the "The ACS Women Chemists Committee Award" (#3), "CCS Celebrates Outstanding Women in Chemistry" (#8), and "Sri Lanka Women Chemists Breakfast" (#33, IUPAC GWB, an example of a cascading effect of the IUPAC GWB on the regional/national level) (Kerton, 2022). In an interview, it was reported that Judith Iriarte-Gross, the recipient of the 2017 ACS Award for Encouraging Women into Careers in the Chemical Sciences, mentioned that she was inspired by E. Ann Nalley, who was the winner of the same award in 2015 (WorldWideLearn, 2021).

In terms of indicator 3.5, "policies", eight initiatives offer some form of policy to support women in STEM. Many programs do not have a hard rule that restricts participation solely to women. For example, the Caltech Women for Chemistry initiative welcomes non-binary persons. The ACS Award for Encouraging Women into Careers in the

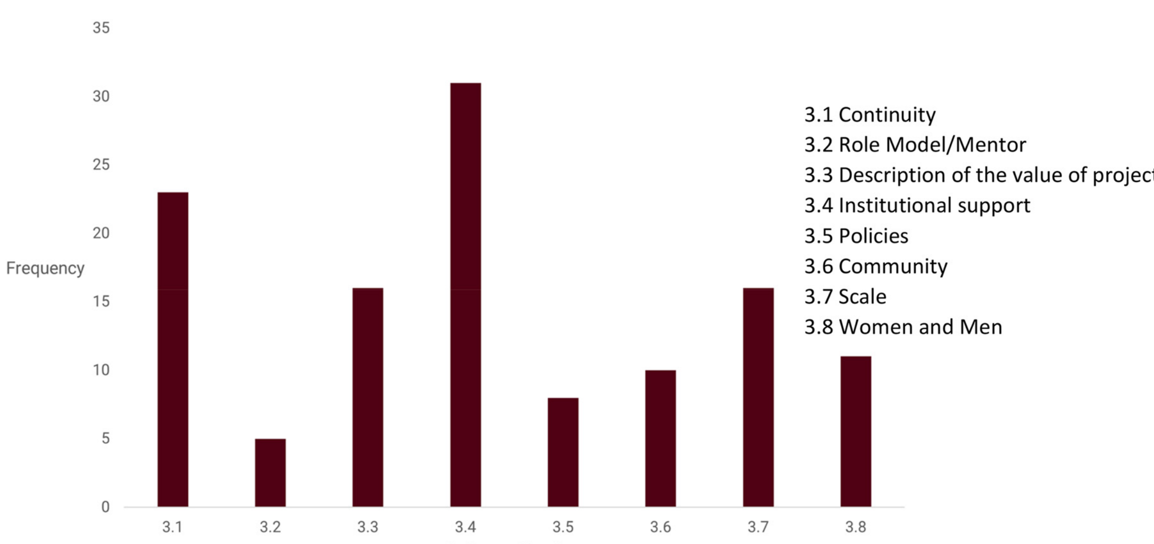

Figure 4: The frequency of initiatives that were coded across the RQ3 indicators.

Chemical Sciences (2024) has flexible requirements, where it welcomes anyone regardless of gender to participate (Wang, 2017). Initiatives that are already women-only will naturally only allow women to participate. An example is the program Magic of Chemistry™ at the University of Nebraska at Omaha which targets only junior Girl Scouts in fourth to eighth grade (#27). This program is offered under the name, Girl Scouts Chemistry Workshop. The frequency of initiatives that were coded across the RQ3 indicators are plotted as shown in Figure 4.

6 Discussion

6.1 The emergent call to policymakers

Based on the findings, we strongly recommend that institutions or associations support young women scientists for their career development and learning. Because every small effort contributes to an overall change, it is crucial to have institutional policies that promote gender equity, as well as alterations to existing practices to reduce unfair biases stemming from past practices. These steps are essential to initiate change. We believe that a multi-faceted approach is necessary. This approach includes education and awareness raising, representation in media, policy, and legislation, and empowering grassroots movements. In our pilot study, we have incorporated the "goals" within the categories derived from our three research questions (RQs) in the survey.

Notably, the survey shows that most of the initiatives are based on the work of university educators and scientists. Moreover, it is difficult to find some form of influence from policymakers. From our professional experience, the authors posit that career guidance is an important segment of the science curricula in secondary schools. As the study by (Rüschenpöhler & Markic, 2020) shows, women students appreciate information from different sources, but individual professional feedback is most impactful. Such mentoring relationships might be difficult to initiate, but their benefits are so important that such relationships are much needed and strongly encouraged. We believe that having the participation of policymakers in formulating initiatives would be paramount to their long-term sustainability. From the findings, there is room for encouraging various stakeholders to put more emphasis on initiating or continuously support this type of programs.

One of the findings about the strategies used for promoting women in chemistry was, encouragingly, the development of policies (see Table 2). Even though the influence of policies in academia might not be as strong as one would hope (e.g., guidance on the numbers of women to be invited as plenary speakers), we consider that initiatives that focus on setting up policies for implementation of gender equity are promising (Ross et al., 2022).

6.2 The need for sustainable activities

Offering information and encouragement on career guidance for girls, young adults, and women early in their careers is particularly important. In primary schools, it is observed that while boys and girls differ marginally in their general attitudes toward science, helping women to see themselves as scientists one day is difficult even at a young age (Carlone et al., 2015). One plausible reason is the paucity of visible female scientists in the STEM field, or perhaps, the over-imbalance of male scientists in STEM fields. Researchers also point out the limited parental encouragement and resources for supporting budding female students' interest in learning science (Archer et al., 2013; DeWitt et al., 2011). Youth competitions in STEM such as the International Chemistry Olympiad (Chang & Fung, 2023; Fung et al., 2017) serves as stepping stones for admission to top universities and future STEM careers (Almukhambetova & Kuzhabekova, 2020). Encouraging budding female scientists to participate in such competitions is helpful in supporting their interests in science. Educating parents and the public about moving from implicit gender biased-mindsets to gender-balanced mindsets is not an easy task for society but it does not mean that it cannot be achieved with continuous and organized effort. This study suggests that participation by men is equally as important as by women in advocating for more gender equity in scientific careers and shifting mindsets of career choices. Mindset shifts are ostensibly closely tied to cultural change, and to bring about such shifts, a change in culture must be actively pursued (Archer et al., 2012; Jayaratne et al., 2003; Lloyd et al., 2018). Cultures are deeply ingrained in society, so transforming them completely can take considerable time. However, every small effort contributes to an overall change. Therefore, it is crucial to have institutional policies that promote gender equity, as well as alterations to existing criteria to reduce unfair biases (even hidden ones) stemming from past practices. These steps are essential to initiate the first phase of change.

Most of the initiatives that support young women and girls focus on conferences, symposia, and workshops. The question, however, remains whether the activities in the initiatives are sustainable over a longer term. This study shows that some of these initiatives started more than 20 years ago. For these and other initiatives, their influence and impact should be measured.

6.3 Identifying role models and mentor systems for girls or women scientists at various levels of the education systems

As stated before, giving awards to identify women scientists as role models (for example, through awards like IUPAC's Distinguished Women in Chemistry or Chemical Engineering and the SNIC-AsCA2019 Distinguished Woman Chemist Awards) can help women students or young scholars develop self-esteem and confidence about themselves (Chiu & Cesa, 2020; Miller-Friedmann et al., 2018; United Nations, 1979). Having consciously seen these visible women scientific leaders recognized ostensibly assures that girls no longer need to expect to play only supporting roles in scientific successes. According to research by Lockwood et al., role models have a powerful impact, especially for women facing gender biases and institutional barriers (European Institute for Gender Equality, 2023). As some individuals put it – "Seeing is believing!" (Plotina, 2023). Role models inspire individuals to aim high and pursue personal and professional success. Witnessing someone they admire achieve great things motivates others to believe in their own potential. Additionally, when individuals from marginalized or underrepresented groups succeed, they become living proof that anyone can overcome obstacles and thrive, regardless of their background (European Institute for Gender Equality, 2023). It is therefore important to conspicuously feature leading women role models in science. In summary, a few projects were identified that met our continuity criteria, as well as enjoying institutional support. Other projects may also serve as role models by including a similar percentage of men and women.

6.4 Recognition and support from institutions

The scientific landscape is often characterized by a hectic pace and an overwhelming workload, encompassing lab and classroom duties, administrative tasks, and a never-ending stream of to-do lists (Lockwood et al., 2004). From our study, programs are primarily supported by universities, institutions, or scientific unions at the local, national, or global level. Such support (regardless of the type of support) is necessary if programs are expected to have continuity and potential impacts in chemistry. We must be aware that such support, either financially or administratively, can send a signal about respect for women's contribution to the scientific disciplines. In a Chinese proverb, you can easily break down one chopstick, but you cannot easily break down a whole bunch of chopsticks. That means we need to have a community or an organization providing long-term support to make good practices visible and respectful.

7 Limitations of this study

This study has several limitations. Firstly, the sampling of initiatives was restricted to languages understood by the researchers, introducing selection bias by omitting initiatives in other major languages like Arabic, Japanese, and Russian. Even if our team understood these languages, many others remain uncovered. Secondly, our search was limited by the accessibility and currency of websites and inherent biases in search engine optimization processes. Some initiatives with significant impact may not have been digitalized. Although this study includes three categories of analysis, conclusions should not be over-generalized due to incomplete data and potential missed updates. Consequently, the actual impact of some initiatives is difficult to judge.

8 Future works

Initiatives aimed at reducing the gender gap in STEM tackle this issue by introducing girls to role models, creating inclusive learning environments, and offering hands-on learning opportunities. Challenges include combating stereotypes and ensuring long-term engagement. These initiatives track participant numbers, measure learning outcomes and gauge career aspirations in STEM fields (Archer et al., 2013, 2014).

To enhance these programs, interviewing or surveying key stakeholders can provide insights into best practices, areas for improvement, and overall effectiveness. A broader investigation of such programs is crucial for developing conclusive recommendations to bridge the gender gap in STEM globally.

9 Conclusions

A broader awareness of the challenges faced by women in STEM highlights the need for deliberate actions to promote and empower women in these fields. Open conversations through symposia, scientific journals, and mentoring programs can contribute to achieving gender equity. The diverse team conducting this review strengthens the originality of our approach, emphasizing the importance of sharing best practices and driving policy changes.

Ongoing discussions are crucial for sharing best practices and driving policy changes, regulations, programs, and training. More research is needed to develop evaluation methods for existing programs and identify exemplars for organizations to emulate. Emphasizing gender-friendly working environments and implementing guidelines for best practices can pave the way for successful, inclusive, and diverse implementation of gender equality. Our work serves as a valuable resource for current and future leaders dedicated to championing this cause and fostering positive change in the scientific community.

Supporting Information

The database of websites and programs used in the review of gender equity and inclusion practices can be found in the Supporting Information (DOCX/PDF).

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