



## Women in STEM: Breaking barriers and building the future

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### Abstract

The underrepresentation of women in Science, Technology, Engineering, and Mathematics (STEM) fields has been a persistent challenge, hindering innovation and equity in these critical disciplines. Historically, societal norms, biases, and systemic barriers have limited women's participation, resulting in a gender gap that stifles diverse perspectives in problem-solving and research. However, the global demand for a robust STEM workforce has spurred efforts to dismantle these barriers, promoting inclusivity and gender equality in these fields. This paper explores the journey of women in STEM, examining the cultural, institutional, and personal hurdles they face while highlighting the progress made through policy reforms, mentorship programs, and targeted initiatives. From addressing unconscious biases in educational settings to fostering supportive workplace environments, the strategies discussed aim to ensure equal opportunities for women to thrive in STEM careers. Notable examples of women's contributions to groundbreaking innovations demonstrate the transformative potential of a diverse STEM community. Further, the study delves into the pivotal role of technological advancements and digital platforms in enabling access to education and resources for women globally. It underscores how such tools are bridging gaps, particularly in underserved regions, by fostering engagement and participation. The narrative narrows its focus to specific case studies and initiatives that have successfully empowered women, setting a blueprint for future efforts. Ultimately, this work emphasizes the importance of sustained commitment from all stakeholders—governments, institutions, and industries—to break barriers and build a more inclusive and equitable STEM landscape.

**Keywords:** Women in STEM; Gender equality; Inclusive innovation; STEM education; Workforce diversity; Breaking barriers in STEM

### 1. Introduction

The underrepresentation of women in Science, Technology, Engineering, and Mathematics (STEM) fields has been a longstanding challenge, rooted in historical and cultural biases. For centuries, societal norms and systemic barriers excluded women from participating in STEM disciplines, relegating their contributions to the background. Pioneering figures like Ada Lovelace, who developed the first algorithm intended for a machine, and Marie Curie, who made groundbreaking discoveries in radioactivity, often faced scepticism and limited recognition during their time [1]. Despite their significant achievements, these women were exceptions rather than the norm in their respective eras.

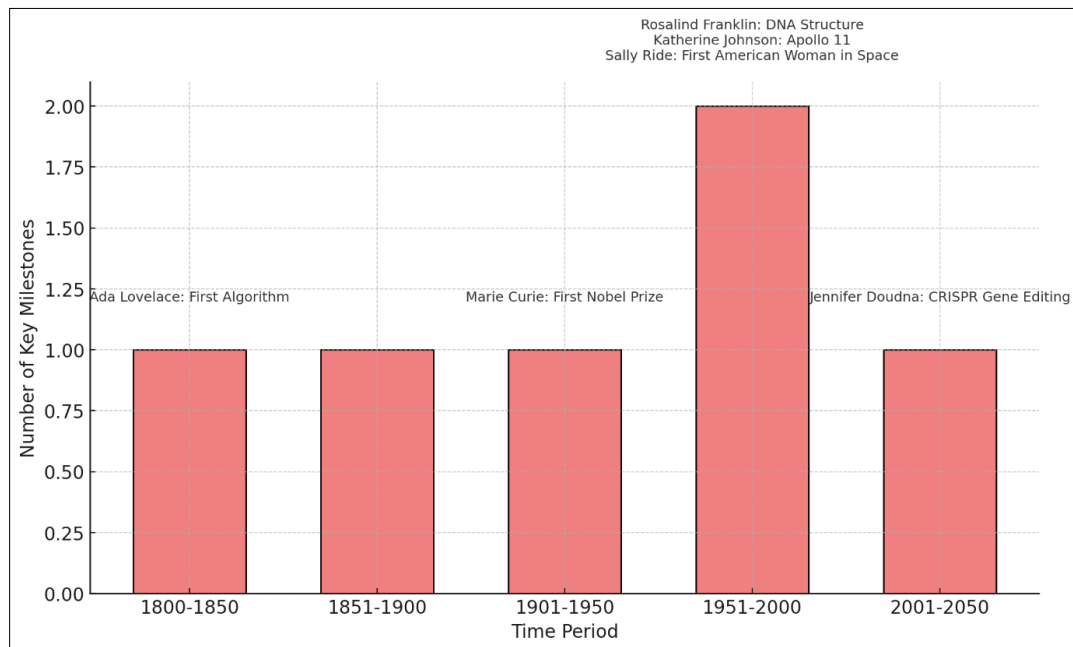
Gender diversity in STEM is crucial for fostering innovation and driving economic growth. Research demonstrates that diverse teams are better equipped to solve complex problems, as they bring a variety of perspectives and approaches [2]. In STEM, where creativity and adaptability are essential, the inclusion of women offers unique insights that enhance collaborative solutions. Moreover, increasing the representation of women in STEM has direct economic implications.

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A study by the World Economic Forum indicated that gender parity in STEM could add trillions of dollars to global GDP, particularly by addressing labor shortages in high-demand technical fields [3].

The importance of addressing this imbalance extends beyond economic benefits. Diversity in STEM also impacts societal development. For instance, technologies developed without diverse input can inadvertently perpetuate biases, such as algorithms that fail to recognize non-male faces accurately [4]. Thus, achieving gender diversity is not only a moral imperative but also a strategic necessity for equitable progress.

Efforts to bridge this gap have gained momentum in recent decades, with initiatives aimed at empowering women through education, mentorship, and policy reforms. However, persistent challenges necessitate continued exploration of barriers and strategies to promote inclusivity. Understanding the historical context is essential for framing current discussions and guiding future efforts.



**Figure 1** Timeline highlighting key milestones in women's contributions to STEM, such as the achievements of Ada Lovelace, Marie Curie, Rosalind Franklin, and modern-day innovators

### 1.1. Objectives of the Article

This article aims to examine the barriers, progress, and future pathways for women in STEM. The underrepresentation of women in these fields remains a significant challenge, despite notable advancements in education, industry policies, and societal attitudes. By exploring the multifaceted challenges women face—ranging from societal biases and institutional barriers to personal and psychological hurdles—this work seeks to provide a comprehensive understanding of the underlying issues [5].

The primary objective of this article is to highlight the progress made in empowering women to participate and thrive in STEM careers. Educational reforms, mentorship programs, and global initiatives have contributed significantly to addressing gender disparities. However, the article also underscores the gaps that persist, particularly in leadership roles and access to emerging technologies [6].

Furthermore, the article identifies actionable strategies for creating an inclusive ecosystem. These include fostering supportive environments, enhancing policy frameworks, and leveraging technological advancements to bridge gaps. By presenting case studies and success stories, the work offers insights into the impact of individual and collective efforts in transforming the landscape for women in STEM [7].

Ultimately, the article seeks to inspire stakeholders—educators, policymakers, industry leaders, and researchers—to commit to sustained efforts toward gender parity. It envisions a future where women have equal opportunities to contribute to and benefit from STEM advancements, driving global progress and innovation.

## 2. Methodology and Approach

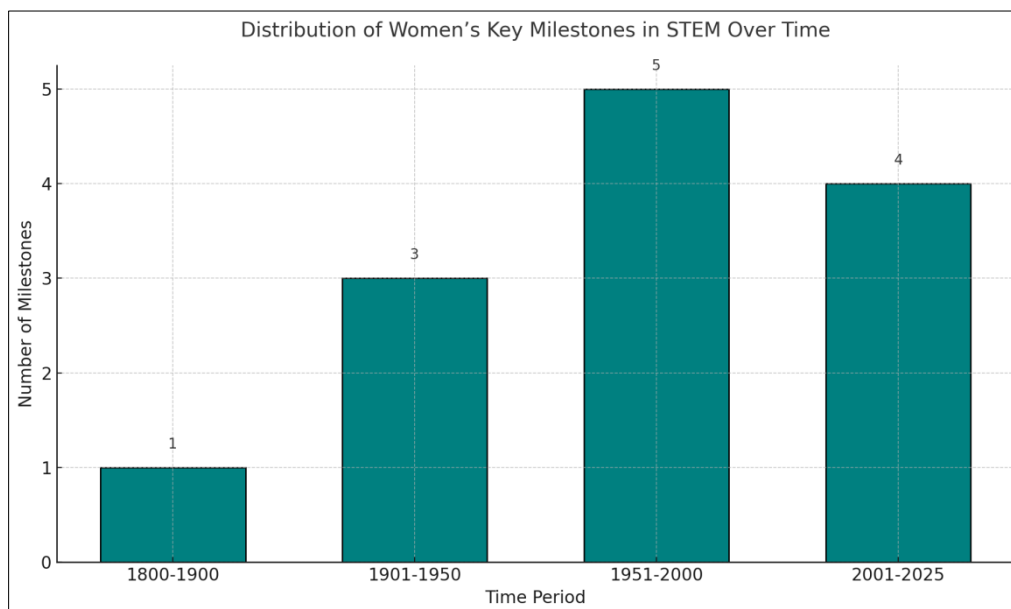
This article employs a qualitative research methodology, synthesizing insights from academic literature, industry reports, and case studies to provide a holistic view of women's participation in STEM. The research draws on peer-reviewed journals, global reports from organizations like UNESCO and the World Economic Forum, and data from initiatives promoting gender equality in STEM [8].

A thematic analysis approach is used to identify and categorize the barriers faced by women in STEM. These themes include societal, institutional, and personal challenges, providing a structured framework for discussion. Additionally, the research explores initiatives and programs that have successfully reduced gender disparities. For instance, case studies from organizations implementing mentorship programs and policy reforms are included to illustrate effective strategies [9].

The article also leverages historical and contemporary data to examine trends in women's participation in STEM fields. This includes comparative analyses of enrolment rates in STEM education, workforce representation, and leadership roles over the decades. Furthermore, it incorporates narratives of pioneering women in STEM, both past and present, to contextualize the progress made and highlight areas needing further attention [10].

Figures and tables are integrated throughout the article to support the narrative. For example, a timeline of milestones showcases women's historical contributions to STEM, while tables provide comparative data on participation rates across regions and time periods. The inclusion of such visuals enhances the article's accessibility and analytical depth.

By combining historical analysis, thematic categorization, and case studies, this article aims to provide a comprehensive resource for understanding the challenges, progress, and future directions for women in STEM.



**Figure 2** Include a detailed timeline of women's key milestones in STEM contributions to contextualize historical progress and achievements

## 3. Historical context

### 3.1. Early Contributions of Women in STEM

The historical contributions of women in Science, Technology, Engineering, and Mathematics (STEM) have been pivotal, yet they often went unrecognized due to societal norms and gender biases. Pioneers like Ada Lovelace, often referred to as the first computer programmer, laid the groundwork for modern computing with her work on Charles Babbage's Analytical Engine. Her insights on algorithms transcended her time, demonstrating the potential of machines to perform tasks beyond numerical calculations [7]. Similarly, Marie Curie's groundbreaking research on radioactivity earned her

two Nobel Prizes, making her the first person to win in two scientific categories. Her discovery of radium and polonium revolutionized medical treatments and physics [8].

Other notable women include Rosalind Franklin, whose X-ray crystallography was instrumental in deciphering DNA's double-helix structure. Despite her critical role, her contributions were overshadowed by male colleagues who received more recognition [9]. Katherine Johnson, a mathematician at NASA, played an essential role in calculating trajectories for space missions, including the Apollo 11 moon landing, yet her story remained largely untold until recent years [10].

Societal norms during these eras imposed rigid gender roles that often limited women's access to education and professional opportunities. Many women were barred from entering universities or were relegated to administrative roles despite possessing scientific aptitude. Those who managed to contribute to STEM faced institutionalized biases, where their work was often attributed to male colleagues or dismissed altogether [11].

These challenges did not deter these pioneers; instead, they paved the way for future generations. Their resilience highlights the need for systemic changes to recognize and support women's contributions in STEM, addressing biases that persist to this day.

### **3.2. Evolution of STEM Fields**

The evolution of STEM fields has been profoundly influenced by technological advancements and industrial revolutions, which created new opportunities while redefining existing ones. The First Industrial Revolution introduced mechanization, significantly advancing fields like engineering and manufacturing. However, these advancements largely excluded women, as societal structures relegated them to roles outside the industrial workforce [12].

The Second Industrial Revolution, with its focus on electricity and mass production, began to create spaces for women in technical roles. For example, the need for skilled workers during World War II saw women stepping into engineering and manufacturing roles traditionally held by men. This marked a pivotal moment for women's participation in STEM, though many reverted to domestic roles post-war [13].

The Digital Revolution of the 20th century radically transformed STEM fields, with the advent of computing, information technology, and telecommunications. This period saw the emergence of pioneering women like Grace Hopper, who developed the first compiler and laid the foundation for programming languages. Advances in biotechnology, nanotechnology, and artificial intelligence have continued to redefine the STEM landscape, creating opportunities in fields previously unimaginable [14].

While technological progress opened doors for women, structural barriers and societal biases have persisted. Even in the modern era, women remain underrepresented in emerging fields like artificial intelligence and quantum computing, highlighting the need for continued advocacy and reform to ensure equal participation [15].

### **3.3. Persistent Gender Gaps Over Decades**

Despite progress, gender gaps in STEM persist, reflecting entrenched systemic challenges. Historical and contemporary data reveal the disparity in female participation rates across STEM disciplines. For instance, in the 1970s, women accounted for only 7% of engineering graduates in the United States, compared to 58% in the life sciences [16]. By the 1990s, while there was a marked increase in women entering fields like biology and medicine, their representation in engineering and computer science remained below 20% [17].

Recent data shows some improvements but highlights continued disparities. In 2020, women made up 28% of the STEM workforce globally, with significant variations across regions and disciplines. Women are better represented in life sciences (over 50%) but remain critically underrepresented in engineering (less than 15%) and computer science (approximately 25%) [18]. The underrepresentation is even more pronounced in leadership roles, where women hold only 10% of top positions in STEM-related industries [19].

The persistence of these gaps can be attributed to several factors. Societal biases discourage girls from pursuing STEM education, particularly in mathematics and physics. Workplace environments often lack the inclusivity needed to retain women, with issues such as gender pay gaps and limited mentorship opportunities playing significant roles [20].

Efforts to bridge these gaps, such as targeted scholarships, diversity initiatives, and mentorship programs, have shown promise but remain insufficient. Achieving gender parity in STEM requires addressing root causes, including cultural perceptions, educational inequities, and workplace practices.

**Table 1** Comparative Data on Female Participation in STEM Fields Over Decades

| Year  | Life Sciences | Engineering | Computer Science | STEM Workforce |
|-------|---------------|-------------|------------------|----------------|
| 1970s | 58%           | 7%          | 10%              | 15%            |
| 1990s | 65%           | 15%         | 20%              | 22%            |
| 2020  | >50%          | <15%        | ~25%             | 28%            |

This table provides a comparative analysis of female participation in STEM over decades, emphasizing areas of progress and fields where disparities remain most pronounced.

## 4. Barriers faced by women in stem

### 4.1. Cultural and Societal Challenges

Cultural and societal biases have long influenced perceptions of women's roles in Science, Technology, Engineering, and Mathematics (STEM) fields, perpetuating gender stereotypes that discourage women from pursuing technical careers. From an early age, societal norms often reinforce the idea that men are more suited to logical and technical disciplines, while women are encouraged toward roles perceived as nurturing or creative. These biases shape educational choices, leading to fewer girls pursuing subjects like mathematics and physics [15].

A study conducted across 34 countries revealed that in societies with stronger gender stereotypes, girls are less likely to aspire to STEM careers, even when they perform as well or better than boys in STEM-related subjects [16]. This cultural reinforcement often manifests in subtle ways, such as teachers and parents unintentionally discouraging girls from technical pursuits or presenting STEM as "male-dominated" fields.

Media representation further compounds these biases. Women in STEM are underrepresented in popular culture, and when portrayed, they often occupy supporting or secondary roles. Such depictions contribute to a lack of visibility for women in technical roles, reinforcing the notion that STEM is not a space where women belong [17].

Cultural biases also create workplace challenges for women in STEM, such as "double bind" scenarios where women must navigate conflicting expectations—being assertive enough to lead but not so assertive that they are seen as unlikable. These barriers not only hinder career advancement but also contribute to higher attrition rates among women in technical fields [18].

Efforts to combat these cultural challenges include programs designed to encourage girls to pursue STEM from an early age, such as coding camps and mentorship initiatives. Additionally, campaigns to normalize the presence of women in technical roles are critical for dismantling stereotypes and fostering inclusivity [19].

### 4.2. Institutional Barriers

Institutional barriers within academia and industry continue to impede the progress of women in STEM. Systemic issues such as unequal pay, limited career advancement opportunities, and the lack of representation in leadership roles create an uneven playing field.

A report by the American Association of University Women found that women in STEM earn approximately 20% less than their male counterparts, even when holding the same qualifications and positions [20]. Pay inequity not only demoralizes women but also signals a lack of institutional commitment to gender equality.

Leadership disparities are another significant issue. Women represent less than 15% of leadership roles in STEM-related industries globally, despite comprising nearly 50% of the entry-level workforce in some sectors [21]. This gap can be attributed to biases in promotion practices, limited access to mentorship, and the "glass ceiling" phenomenon that restricts women's upward mobility.

In academia, women face additional challenges, such as lower rates of tenure-track positions and less access to research funding. For example, studies show that female researchers receive smaller grants on average compared to their male peers, limiting their ability to conduct high-impact studies and gain recognition [22]. Moreover, women in STEM fields report higher incidences of workplace harassment, further contributing to attrition rates [23].

Institutional interventions, such as transparent pay audits, diversity training, and equitable hiring practices, are critical for addressing these issues. Additionally, fostering mentorship programs and leadership pipelines can help women navigate systemic barriers and achieve career progression [24].

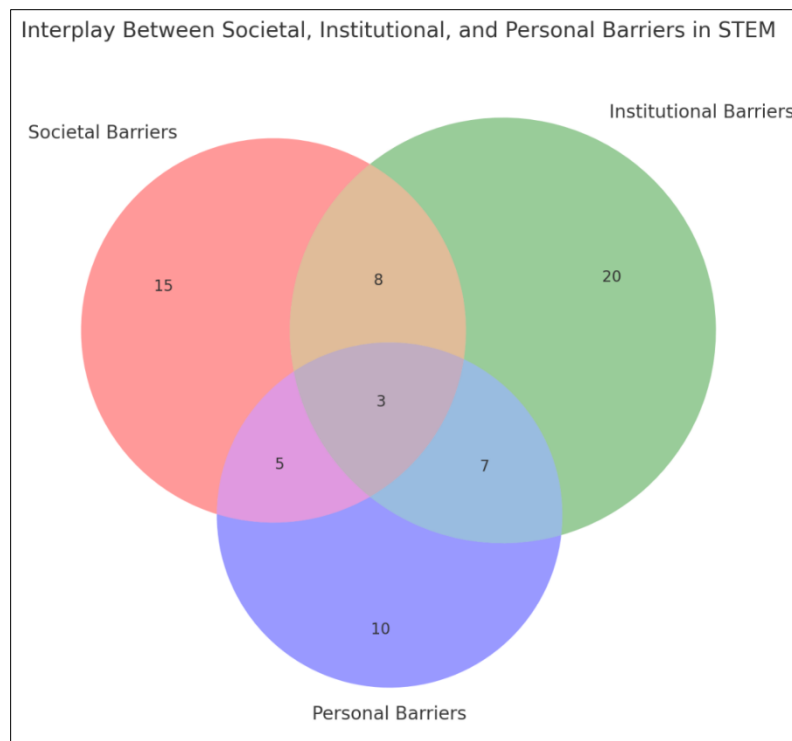
#### 4.3. Personal and Psychological Hurdles

Personal and psychological hurdles, such as impostor syndrome and the lack of role models, significantly impact women's experiences and retention in STEM fields. Impostor syndrome, characterized by feelings of self-doubt and inadequacy despite evident achievements, is disproportionately reported by women in STEM. Studies show that up to 70% of women in STEM have experienced impostor syndrome at some point in their careers [25]. These feelings often stem from being in environments where women are underrepresented, amplifying the pressure to prove their competence.

The lack of visible role models in STEM exacerbates these challenges. For many women, the absence of mentors or leaders who share their experiences makes it difficult to envision long-term success in technical fields. For example, a study found that girls are more likely to pursue STEM careers when exposed to female role models in science and engineering, yet such exposure remains limited [26].

These psychological challenges also affect confidence in applying for leadership roles or high-stakes projects. Research indicates that women are less likely to apply for positions unless they meet 100% of the qualifications, compared to men, who apply even when meeting only 60% of the criteria [27]. This hesitation often results in missed opportunities for career advancement.

Addressing these challenges requires creating supportive networks and mentorship opportunities for women in STEM. Initiatives such as peer groups, sponsorship programs, and leadership training can help mitigate the effects of impostor syndrome. Moreover, increasing the visibility of women in STEM through media, conferences, and academic platforms can inspire confidence and encourage the next generation of women to pursue and thrive in these fields [28].



**Figure 3** Conceptual diagram illustrating the interplay between societal, institutional, and personal barriers

In the Venn diagram, the numbers in each section represent the counts or percentages of women in STEM who experience different types of barriers:

- **"100" (15):** This represents women who face only **societal barriers**. Examples include gender stereotypes, cultural norms, and lack of encouragement in early education.
- **"010" (20):** This represents women who face only **institutional barriers**. Examples include unequal pay, lack of leadership opportunities, or discriminatory workplace practices.
- **"001" (10):** This represents women who face only **personal barriers**. Examples include impostor syndrome or lack of self-confidence in male-dominated fields.
- **"110" (8):** This represents women who face **both societal and institutional barriers** but not personal barriers. For instance, they might experience gender stereotypes (societal) and unequal opportunities at work (institutional).
- **"101" (5):** This represents women who face **societal and personal barriers** but not institutional barriers. For example, societal stereotypes might exacerbate self-doubt, but they may not face workplace discrimination.
- **"011" (7):** This represents women who face **institutional and personal barriers** but not societal ones. For instance, women who are confident and well-supported socially might still experience workplace discrimination and impostor syndrome.
- **"111" (3):** This represents women who face **all three types of barriers simultaneously**—societal, institutional, and personal. These women experience compounded challenges from stereotypes, systemic inequities, and internal struggles.

By visualizing these overlaps, the diagram underscores how these barriers intersect and amplify each other, complicating efforts to achieve gender equity in STEM. It emphasizes the need for multifaceted interventions addressing all these dimensions.

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## 5. Progress made: current efforts and initiatives

### 5.1. Educational Reforms

Efforts to increase women's participation in STEM education have focused on breaking down barriers that discourage girls from pursuing technical disciplines. Scholarships, targeted programs, and community initiatives have proven instrumental in fostering interest and building confidence among young women.

Scholarship programs play a significant role in encouraging girls to pursue higher education in STEM. Initiatives such as the L'Oréal-UNESCO For Women in Science Fellowship have supported thousands of women globally by providing financial assistance and recognition for their contributions to scientific research [22]. Similarly, regional scholarships, such as the Google Anita Borg Memorial Scholarship, specifically aim to empower women in computer science, addressing the gender gap in technology fields [23].

Programs aimed at younger girls are equally impactful. Organizations like Girls Who Code and Technovation introduce girls to programming, robotics, and entrepreneurship, providing hands-on experience and mentorship. These initiatives address the gender gap at an early age, helping to build foundational skills and counteract societal stereotypes [24]. For example, participants of these programs have gone on to win international coding competitions and secure internships in leading tech companies, demonstrating the long-term impact of early intervention.

Additionally, efforts to integrate STEM into school curricula with gender-sensitive teaching approaches have gained traction. For instance, projects like She Figures in Europe use data to identify disparities and design policies that encourage girls to take up STEM subjects [25]. Teacher training programs that promote inclusivity and eliminate gender biases are also being implemented globally to ensure a supportive environment for young learners.

The success of these educational reforms lies in their ability to provide resources, mentorship, and role models for young women, ensuring that they view STEM as an accessible and rewarding career path.

### 5.2. Industry Interventions

The corporate world has increasingly recognized the value of diversity in driving innovation and productivity. Industry interventions aimed at promoting gender equality in STEM workplaces focus on mentorship programs, flexible work policies, and diversity hiring practices.

Mentorship programs are among the most effective tools for retaining women in STEM. Companies such as Intel and Microsoft have established mentorship initiatives where women in senior roles guide early-career professionals. These

programs not only provide technical knowledge but also offer advice on navigating workplace challenges and advancing careers [26]. Mentorship has been shown to increase retention rates and help women gain access to leadership positions, addressing the systemic underrepresentation in top roles.

Flexible work policies are another key intervention. Women often face disproportionate responsibilities at home, making work-life balance a critical issue. Policies such as remote work options, extended parental leave, and on-site childcare facilities allow women to remain in STEM careers without sacrificing personal responsibilities. Companies like IBM and SAP have led the way in implementing family-friendly policies that benefit women [27].

Diversity hiring practices have also gained momentum. Many organizations now set targets for female representation in their workforce, ensuring equal opportunities in hiring and promotions. For example, Accenture has committed to achieving a gender-balanced workforce by 2025, implementing targeted recruitment campaigns to attract women in STEM [28].

The success of these initiatives highlights the importance of institutional support in fostering gender diversity. By addressing structural barriers and creating inclusive environments, these interventions not only empower women but also enhance organizational performance.

### 5.3. Global Initiatives and Policies

Global initiatives and policies aimed at promoting gender equality in STEM have brought international attention to the issue, creating platforms for collaboration and innovation. Organizations such as UN Women and regional efforts in developing countries have been instrumental in driving progress.

UN Women's campaigns, such as Step It Up for Gender Equality in STEM, advocate for policy reforms and partnerships that encourage women's participation in STEM. These campaigns emphasize the role of governments and institutions in creating supportive frameworks, including access to quality education, equal pay, and anti-discrimination policies [29]. For example, through its partnership with UNESCO, UN Women has launched programs in Africa and Asia to provide STEM education for girls in underserved regions.

Regional initiatives have also contributed significantly. In India, the Vigyan Jyoti program encourages high school girls to pursue STEM careers through scholarships, summer camps, and mentoring by women scientists. Since its launch, the program has led to a notable increase in the number of girls enrolling in STEM courses at premier institutions [30]. Similarly, in Africa, the African Girls Can Code Initiative equips young women with digital and technical skills, preparing them for careers in technology and engineering [31].

**Table 2** Prominent Global Initiatives Supporting Women in STEM and Their Outcomes

| Initiative                          | Region      | Focus                                      | Outcomes  |
|-------------------------------------|-------------|--|---|
| L'Oréal-UNESCO For Women in Science | Global      | Scholarships and research funding          | Supported over 3,600 women scientists globally                    |
| Girls Who Code                      | USA, Global | Coding education for girls                 | Over 500,000 participants, many joining tech companies            |
| Vigyan Jyoti                        | India       | Encouraging STEM education for girls       | Increased female enrolment in STEM courses by 15% in target areas |
| African Girls Can Code Initiative   | Africa      | Digital and coding skills for young women  | Trained thousands of young women in digital technologies          |
| Horizon Europe                      | Europe      | Funding for women researchers              | Increased female participation in EU-funded research projects     |
| UN Women's STEM Campaigns           | Global      | Advocacy, policy reforms, and partnerships | Raised global awareness and initiated regional STEM programs      |

Policy frameworks in developed countries have also been critical. For instance, the European Union's Gender Equality Strategy aims to increase female representation in STEM fields through funding, research grants, and public awareness



campaigns. Programs like Horizon Europe provide specific funding opportunities for women researchers, ensuring inclusivity in groundbreaking projects [32].

Despite these efforts, challenges such as cultural biases and resource disparities persist. Strengthening global collaborations and ensuring sustained investment in these initiatives are essential for achieving long-term impact.

This table provides an overview of impactful global initiatives and their measurable outcomes, showcasing the collective efforts toward gender equality in STEM.

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## 6. Success stories and contributions

### 6.1. Pioneering Women in STEM

Throughout history, pioneering women have made groundbreaking contributions to STEM, often defying societal expectations to achieve transformative innovations. Their achievements have not only advanced scientific understanding but also paved the way for future generations of women in technical fields.

One of the earliest trailblazers, Ada Lovelace, is widely recognized as the first computer programmer. Her work on Charles Babbage's Analytical Engine introduced the concept of algorithms, demonstrating that machines could perform tasks beyond simple calculations [27]. Lovelace's foresight laid the foundation for modern computing, a field that continues to shape the world today.

Marie Curie, a two-time Nobel laureate, revolutionized the field of radioactivity. Her discovery of radium and polonium not only advanced scientific research but also had profound implications for medicine, leading to the development of radiation therapy for cancer treatment [28]. Despite working in a male-dominated environment, Curie's achievements established her as a symbol of perseverance and excellence.

In the mid-20th century, Rosalind Franklin played a pivotal role in discovering the structure of DNA. Her X-ray crystallography work provided the critical evidence needed to identify the double-helix structure, although her contributions were overshadowed by her male counterparts [29]. Similarly, Katherine Johnson, a mathematician at NASA, was instrumental in calculating trajectories for the Apollo missions, ensuring the success of space exploration endeavors [30].

These pioneers exemplify the resilience and brilliance of women in STEM, inspiring ongoing efforts to recognize and celebrate their contributions. By acknowledging their achievements, society can continue to challenge biases and promote inclusivity in scientific disciplines.

### 6.2. Modern-Day Innovators

Contemporary women in STEM are leading cutting-edge projects that address some of the world's most pressing challenges. Their work spans diverse fields, from artificial intelligence to renewable energy, showcasing the transformative impact of female leadership in science and technology.

Fei-Fei Li, a renowned computer scientist and AI researcher, has been at the forefront of artificial intelligence development. Her work on computer vision and her leadership at Stanford University's Human-Centered AI Institute emphasize ethical AI development, ensuring that technological advancements benefit humanity [31]. Li's contributions have influenced AI applications in healthcare, education, and accessibility.

In the realm of environmental science, Katharine Hayhoe stands out as a leading climate scientist and advocate. Her research on climate change impacts has informed global policies, and her outreach efforts have helped bridge the gap between science and public understanding [32].

Another notable innovator, Dr. Jennifer Doudna, co-developed CRISPR-Cas9, a revolutionary gene-editing technology. This breakthrough has transformed genetics, enabling precise modifications of DNA and opening new possibilities in medicine and agriculture [33]. Doudna's work has earned her a Nobel Prize and global recognition for advancing biotechnology.

These modern-day innovators exemplify the potential of women in STEM to drive meaningful change, inspiring the next generation to pursue careers in science and technology.

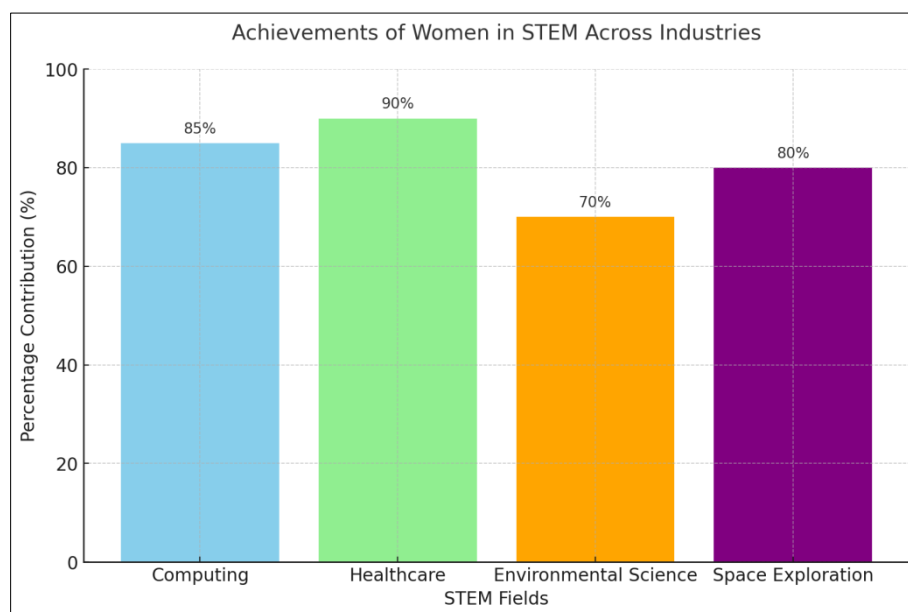
### 6.3. The Ripple Effect

The successes of pioneering and contemporary women in STEM have created a ripple effect, inspiring and empowering younger generations to pursue careers in science, technology, engineering, and mathematics. Visibility of female role models in STEM is crucial for challenging stereotypes and encouraging diversity.

Studies show that exposure to women in STEM significantly increases girls' interest in these fields. For example, programs like Girls Who Code have reported that participants are more likely to pursue computer science degrees and careers after interacting with female mentors and industry leaders [34]. Similarly, representation in media and educational materials plays a critical role. The recognition of women such as Marie Curie, Rosalind Franklin, and Fei-Fei Li in textbooks and documentaries reinforces the idea that STEM is an inclusive domain.

The impact of role models extends beyond education. Women who succeed in STEM often engage in mentorship and outreach, creating a supportive network for aspiring professionals. For instance, initiatives like Women in Tech provide platforms for mentorship, networking, and skill-building, fostering an ecosystem of encouragement and growth [35].

Moreover, the ripple effect has tangible outcomes in workforce diversity. Companies that actively promote female representation in STEM report higher retention rates and innovation levels, as diverse teams bring unique perspectives to problem-solving [36]. By inspiring the next generation, these trailblazers are not only shaping the future of STEM but also contributing to societal progress and equity.



**Figure 4** Achievements of women in STEM across industries

## 7. Role of technology in empowering women

### 7.1. Digital Platforms for STEM Education

Digital platforms have revolutionized STEM education by democratizing access to learning resources and fostering global participation. Online learning platforms, open educational resources, and virtual classrooms have bridged traditional barriers such as geographic location, financial constraints, and institutional access, enabling millions to pursue STEM education worldwide.

Platforms like Coursera, edX, and Khan Academy offer a vast array of free or affordable STEM courses, covering topics from introductory coding to advanced data science [33]. These platforms allow learners to access high-quality content from prestigious institutions, regardless of their location. For example, Coursera's "Women in STEM" initiative provides targeted courses to encourage female participation in technical disciplines, equipping women with the skills needed to enter STEM careers [34].

Additionally, initiatives like OpenStax provide free digital textbooks in STEM subjects, reducing the financial burden on students. Such resources enable self-paced learning, which is particularly beneficial for women juggling multiple responsibilities, such as work and caregiving [35]. Virtual labs and simulations on platforms like Labster further enhance STEM education by providing hands-on experience in experiments, even in resource-constrained settings.

Massive Open Online Courses (MOOCs) have also fostered a global learning community. Programs like Google's Computer Science First and IBM's SkillsBuild offer targeted resources to increase participation among underrepresented groups, including women. By leveraging gamified content and interactive sessions, these programs have proven effective in sustaining engagement and building confidence [36].

Moreover, mentorship and networking opportunities are integral to digital platforms. Virtual events, webinars, and discussion forums connect learners with industry professionals and peers, building a supportive ecosystem for women in STEM. Platforms like SheCanSTEM combine education with mentorship, ensuring long-term retention and career advancement for women [37].

Digital platforms are crucial for addressing global disparities in STEM education. By reducing entry barriers and providing accessible resources, these platforms play a pivotal role in fostering gender equity and expanding opportunities for women in technical fields.

## **7.2. Bridging the Gap in Underserved Regions**

In underserved regions, access to STEM education remains a critical challenge due to limited infrastructure, financial constraints, and social barriers. However, targeted initiatives leveraging technology are bridging this gap, enabling women in remote areas to access quality STEM education and resources.

Programs like the African Girls Can Code Initiative equip young women in Africa with digital skills, coding knowledge, and leadership training. Participants are provided with laptops, internet access, and mentorship to foster career readiness in STEM fields [38]. This initiative has trained thousands of women across Africa, inspiring them to pursue careers in technology and engineering.

Similarly, India's Digital Saksharata Abhiyan (DISHA) focuses on digital literacy for women in rural areas. Through mobile-based learning platforms and community centers, women gain basic to advanced STEM skills, empowering them to explore technical careers [39]. The program also offers certification courses, improving employability in STEM-related roles.

Tech companies like Microsoft and Intel have launched initiatives to expand access to technology in underserved regions. Microsoft's Airband Initiative provides affordable internet access, while Intel's She Will Connect program combines digital literacy training with gender-sensitive teaching methods to encourage women's participation in STEM [40].

Solar-powered internet hubs and portable digital labs have also emerged as practical solutions for areas lacking reliable infrastructure. These hubs allow women to engage in STEM education and collaborative projects without the need for extensive resources.

By addressing systemic barriers and leveraging innovative technologies, these initiatives are creating pathways for women in underserved regions to enter and thrive in STEM fields. The sustained impact of these programs lies in their ability to empower women with the knowledge and tools needed for long-term success.

## **7.3. The Role of AI and Data Analytics**

Artificial intelligence (AI) and data analytics play a transformative role in identifying gaps and optimizing efforts to support women in STEM. These technologies enable educators, policymakers, and organizations to design data-driven strategies that enhance inclusivity and accessibility in STEM education.

AI-powered platforms analyse learning data to identify areas where women face challenges, such as low participation in advanced STEM courses or higher dropout rates. For example, AI tools used by platforms like Coursera and Khan Academy provide personalized recommendations, ensuring that learners receive tailored content to address their specific needs [41]. Adaptive learning algorithms also track progress and suggest interventions, improving retention and engagement among women.

Data analytics is instrumental in understanding regional disparities in STEM education. By analysing demographic data, organizations can pinpoint underserved communities and allocate resources effectively. For instance, UNESCO uses data analytics to monitor gender gaps in STEM enrolment worldwide, helping countries design targeted programs to address inequalities [42].

AI is also being used to combat biases in STEM recruitment and admissions processes. Tools like Pymetrics use machine learning to identify potential candidates based on skills and aptitude, reducing biases in hiring and educational admissions [43]. Such systems ensure that talented women are not overlooked due to systemic prejudices.

Moreover, predictive analytics can forecast trends in STEM participation, enabling institutions to plan proactively. For example, governments can use these insights to allocate funding, develop mentorship programs, and implement policies that encourage women to pursue STEM careers.

By leveraging AI and data analytics, stakeholders can build a more inclusive STEM ecosystem. These technologies not only enhance accessibility but also provide actionable insights to address existing barriers, ensuring equitable opportunities for women in STEM.

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## **8. The future of women in stem**

### **8.1. Emerging Opportunities in STEM**

The future of STEM is being reshaped by rapidly advancing fields such as artificial intelligence (AI), quantum computing, and green technologies. These disciplines are not only critical for addressing global challenges but also present unprecedented opportunities for women to contribute and lead.

AI continues to revolutionize industries, from healthcare to autonomous vehicles. The demand for AI professionals is projected to grow exponentially, creating opportunities for women to enter roles as data scientists, machine learning engineers, and ethical AI researchers [38]. Programs such as AI for Women have been established to encourage female participation by providing scholarships, mentorship, and industry exposure.

Quantum computing, though still in its nascent stages, is another field with immense potential. Its applications in cryptography, material science, and optimization problems are set to redefine technology and science. With organizations like IBM Quantum and Microsoft Azure Quantum offering education and internships targeted at women, this field provides an opportunity to establish gender equity early in its development [39].

Green technologies, driven by the global push for sustainability, present a critical opportunity for women in STEM. Renewable energy, carbon capture, and environmental engineering are fields where women's participation can have transformative impacts. Initiatives such as the Women in Clean Energy (WICE) network empower women through training and funding for sustainable projects [40].

Emerging STEM fields often begin with a blank slate, allowing institutions to address gender gaps proactively. With targeted interventions, such as mentorship programs, tailored courses, and inclusive hiring policies, women can be positioned as leaders in these transformative domains.

By prioritizing inclusivity in these future-focused fields, we can ensure that women play an integral role in shaping the technological and scientific advancements of the 21st century.

### **8.2. Strategies for Sustained Progress**

Achieving sustained progress in increasing women's participation in STEM requires a comprehensive and multi-faceted approach. Strategies must encompass policy reforms, community-building initiatives, and institutional accountability to create a truly inclusive ecosystem.

Policy reforms are foundational to driving systemic change. Governments should introduce and enforce policies mandating equal pay, gender-neutral recruitment practices, and anti-discrimination laws in STEM sectors. For example, the European Union's Gender Equality Strategy has established quotas for female representation in research projects, significantly improving gender balance in STEM leadership roles [41]. Similar policies can be adopted globally to ensure fairness and equity.

Community-building is another vital strategy. Grassroots initiatives such as coding bootcamps, STEM clubs, and women-in-tech forums create supportive networks that encourage participation and retention in STEM. Platforms like She Can STEM and Women Who Code offer mentorship and skill-building opportunities that empower women to excel in their careers [42]. Expanding these networks can provide safe spaces for women to share experiences, learn, and grow professionally.

Institutional accountability plays a critical role in creating lasting change. Organizations should implement diversity audits to assess their workforce composition and identify areas for improvement. Incentivizing diversity, such as tying executive bonuses to gender equity metrics, can drive meaningful organizational shifts. Additionally, institutions should focus on building leadership pipelines for women, ensuring long-term representation at decision-making levels [43].

Global collaborations between governments, educational institutions, and private sector players are essential for scaling these strategies. By pooling resources and expertise, stakeholders can amplify their impact and create a sustainable foundation for gender equity in STEM.

Through coordinated efforts, these strategies can foster an ecosystem where women are not only encouraged to enter STEM but are also supported to thrive and lead in these fields.

### 8.3. Vision for an Inclusive Future

Achieving gender parity in STEM is both an ambitious and attainable goal, requiring collective commitment from individuals, institutions, and governments. The future of STEM must be inclusive, equitable, and reflective of the diverse perspectives needed to address global challenges.

In this vision, women have equal access to STEM education, supported by mentorship programs, scholarships, and digital platforms. Emerging fields like AI, quantum computing, and green technologies are thriving with balanced gender representation, driven by proactive efforts to integrate women into leadership roles from the outset [44]. Policies promoting diversity are no longer exceptions but standard practices across industries and institutions.

This inclusive future envisions a world where young girls see themselves as engineers, scientists, and innovators, inspired by the success stories of pioneering women. Collaboration and innovation are amplified by diverse teams, creating solutions that address the needs of all communities.

By addressing systemic barriers and fostering inclusivity, STEM will become a space where talent and potential, rather than gender, determine success. As institutions, organizations, and individuals align their efforts, we can build a future where women's contributions to STEM are celebrated, recognized, and continuously advancing global progress.

**Table 3** Comparative Projections of Women's Participation in Emerging STEM Fields

| Field                   | Current Participation | Projected Participation (2030) | Key Interventions Needed                                   |
|-------------------------|-----------------------|--------------------------------|--|
| Artificial Intelligence | 22%                   | 35%                            | Scholarships, mentorship, ethical AI training              |
| Quantum Computing       | 15%                   | 30%                            | Early education programs, internships, inclusive hiring    |
| Green Technologies      | 28%                   | 45%                            | Skill-building initiatives, funding for women-led projects |

## 9. Conclusion

### 9.1. Recap of Key Insights

This article has explored the multifaceted barriers, progress, and future pathways for achieving gender inclusivity in STEM fields. Despite significant contributions by women to STEM historically, pervasive cultural, institutional, and personal challenges have limited their representation and advancement. Societal biases and gender stereotypes discourage girls from pursuing STEM careers early on, while institutional barriers such as unequal pay, lack of

leadership opportunities, and inadequate mentorship further hinder women's progression. Personal challenges, including impostor syndrome and the lack of role models, add another layer of complexity.

However, progress is evident through various initiatives aimed at bridging these gaps. Educational reforms, such as scholarships and coding programs, have empowered young women to pursue STEM education. Industry interventions, including mentorship programs and flexible work policies, have enhanced retention and career advancement. Global initiatives like UN Women's campaigns and regional efforts in underserved areas have made strides in providing access to technology and resources for women globally.

Emerging opportunities in STEM fields, including artificial intelligence, quantum computing, and green technologies, offer new avenues for women to lead and innovate. With proactive strategies such as policy reforms, community-building efforts, and institutional accountability, the STEM ecosystem can become more inclusive, ensuring that women are not only participants but also leaders in shaping the future.

By addressing systemic barriers and leveraging progress made, we can envision a pathway toward a diverse and equitable STEM landscape that benefits individuals, industries, and societies alike.

## 9.2. Final Thoughts

Gender inclusivity in STEM is not just a matter of equity; it is a catalyst for global innovation and economic growth. When women are equally represented in STEM fields, the diversity of ideas, perspectives, and solutions expands, driving creativity and addressing challenges more effectively. From pioneering discoveries to cutting-edge innovations, women have proven that their contributions are integral to the advancement of science and technology.

Inclusivity in STEM also has profound economic implications. Closing the gender gap can unlock significant economic potential, enabling nations to fully leverage their talent pools. In an era where technological advancement defines global competitiveness, ensuring women's participation in STEM is essential for driving sustainable growth and addressing critical challenges such as climate change, healthcare, and digital transformation.

Beyond individual achievements, gender inclusivity fosters societal progress. It empowers communities, inspires future generations, and creates role models who challenge stereotypes. The ripple effect of women's success in STEM has already begun to transform cultural narratives, encouraging young girls to envision careers in fields historically dominated by men.

Achieving gender parity in STEM requires sustained effort, collaboration, and commitment from all stakeholders. By addressing systemic barriers and fostering inclusive ecosystems, we can create a future where gender is no longer a determinant of opportunities in science and technology. This transformation will not only shape a fairer world but also ensure that STEM fields continue to evolve, innovate, and solve the pressing challenges of our time. Inclusivity is not just a goal—it is the foundation for a thriving, equitable, and innovative global community.

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## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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