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Tracing Gender Equity in STEM: A Bibliometric Analysis of Women Representation in STEM Education

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Abstract

Advancing gender parity in STEM education remains a global priority, yet persistent inequities continue to limit women's participation and leadership in science and technology fields. This study examines the intellectual structure and evolving research trends on gender parity in STEM education through a comprehensive bibliometric analysis of women's representation in science and technology. Drawing on 585 publications indexed in the Scopus database from 2000 to 2024, the study employs co-citation and co-word analyses to map thematic clusters, identify influential works, and forecast future research directions. Three major co-citation clusters emerged: (1) identity formation, stereotypes, and structural barriers influencing women's participation in STEM; (2) structural barriers, role models, and challenges intensified by the pandemic; and (3) psychological constructs and multi-factorial barriers affecting engagement and persistence. Co-word analysis further revealed dominant trends around diversity and inclusion, representation in policy, and educational innovation in higher education. Despite the field's growth, critical gaps remain in intersectional approaches, longitudinal studies, and evaluations of systemic policy reforms. This study not only synthesizes the knowledge landscape of gender parity research but also underscores its practical significance. It offers actionable insights for scholars, educators, and policymakers by highlighting the need for inclusive pedagogies, institutional reforms, mentorship structures, and targeted interventions, including teacher-training programs that emphasize gender-responsive pedagogy, to improve participation, retention, and leadership pathways for women in STEM.

Introduction

Achieving gender parity in science, technology, engineering, and mathematics (STEM) remains a critical global objective due to its implications for human capital development, innovation, and progress toward the Sustainable Development Goals (SDGs), particularly SDG 4 (quality education) and SDG 5 (gender equality) (UNESCO, 2025a; 2025b). Inclusive participation in STEM fields fosters a broader and more diverse knowledge base, encourages socially responsive innovation, and enhances economic resilience. However, despite longstanding global and national efforts, women continue to be underrepresented across the STEM pipeline, from early childhood exploration and secondary education to postgraduate research and senior academic or industry roles (Smith & White, 2024; Wang & Degol, 2017).

Persistent gender disparities in STEM are not solely attributable to individual choice or academic preparation; they are deeply embedded within sociocultural structures, institutional practices, and early-life socialization processes (Miner et al., 2018). For example, Stephenson et al. (2022) demonstrated that gendered microaggressions in preschool settings often dissuade girls from participating in science-related play, reinforcing early detachment from STEM activities. Even when brief interventions such as exposure to female role models have been shown to increase self-efficacy and STEM aspirations among adolescent girls (González-Pérez et al., 2020), the broader academic and professional environment continues to reproduce exclusionary norms and reduce women’s sense of belonging (Moss-Racusin et al., 2018).

Furthermore, institutional and national efforts to increase girls’ participation in STEM subjects have often yielded inconsistent or marginal results. For example, longitudinal analyses in the United Kingdom suggest that despite awareness campaigns and policy efforts, female students' uptake of subjects such as physics and computing has not substantially improved over time (Smith & White, 2024). Similarly, in higher education, women remain disproportionately represented in certain disciplines and face significant challenges in advancing to doctoral-level study or leadership roles in engineering and technology fields (Elmer et al., 2024). This body of research points to three significant gaps. First, longitudinal evidence is lacking to assess whether early interventions yield long-term impacts on girls’ educational and career trajectories in STEM. Second, while gender is frequently studied as a binary variable, there is insufficient attention to how it intersects with other dimensions of identity, such as socioeconomic status, ethnicity, or disability. Third, few comparative evaluations exist of system-level reforms such as flexible working arrangements, inclusive curricula, or structured mentorship that could enable sustainable gender inclusion in STEM fields across diverse contexts (Cheryan et al., 2017; Mathew et al., 2024).

The present study addresses these gaps by conducting a bibliometric analysis to map the intellectual structure and emerging trends in gender parity research within STEM education. Specifically, the study employs co-citation analysis to uncover the thematic clusters of existing literature and co-word analysis to forecast future research directions. Through this approach, the study seeks to provide a comprehensive synthesis of current knowledge, identify underexplored areas, and offer data-driven recommendations to inform inclusive education policies and practices. By situating gender parity in STEM education within global, intersectional, and developmental frameworks, the study aims to contribute to building a more equitable and resilient scientific community.

Literature Review

Early Childhood and Gendered Socialization

Early childhood has been widely recognized as a formative period during which gender norms and STEM-related identities begin to take shape. The social cognitive theory emphasizes that children learn gendered behaviours through observation and reinforcement, with implications for how they engage in play and learning (Bussey & Bandura, 1999). Stephenson et al. (2021) found that in Australian preschools, girls were routinely steered away from science-related play due to subtle microaggressions and gendered expectations. However, girls' participation significantly increased when educators adopted the Conceptual PlayWorld framework, which involves teachers acting as co-players in science-themed narratives. These findings underscore the critical role of teacher practices in shaping early STEM identity development.

Similar patterns have been observed in low- and middle-income countries, where sociocultural norms, family expectations, and resource constraints often further inhibit girls' access to STEM learning opportunities (Lasekan et al., 2024). In many African contexts, for example, domestic responsibilities assigned to girls limit their engagement in exploratory and computational play, which are foundational for STEM skills. These insights indicate the need for gender-sensitive pedagogical interventions as early as preschool to counteract entrenched stereotypes.

Adolescence and Academic Identity Formation

Adolescence is a key developmental stage for the formation of academic and career intentions. Empirical studies have demonstrated that exposure to female STEM professionals can significantly enhance girls' motivation, self-efficacy, and perceived belonging in STEM disciplines (González-Pérez et al., 2020). Conversely, environments perceived as gender-biased have been shown to reduce women's interest and persistence in STEM, even when objective performance is unaffected (Moss-Racusin et al., 2018). These dynamics highlight the importance of contextual and psychological factors in shaping adolescent girls' educational trajectories. Cheryan et al. (2017) found that classroom materials and learning environments that subtly reinforce male dominance in STEM can deter girls from pursuing these subjects, even when they perform equally well. Therefore, efforts to improve gender parity must extend beyond curricular content to encompass broader cultural representations and classroom climates that either encourage or inhibit participation.

Institutional Structures and Curriculum Design

Institutional policies and school structures play a significant role in enabling or hindering gender equity in STEM. El Nagdi and Roehrig (2019), in a case study of an all-girls STEM secondary school in Egypt, found that equity-oriented pedagogy, mastery-based assessments, and mentorship opportunities contributed to stronger STEM identities among female students. However, these practices remain exceptions rather than norms. National data from the United Kingdom show only incremental increases in girls' enrollment in traditionally male-dominated STEM subjects despite several national interventions (Smith & White, 2024). These findings suggest that without systemic change, isolated efforts may not yield meaningful long-term impacts. Similar constraints emerge in South Asia. Daraz et al. (2024) reported that in Pakistan's Malakand Division, support from educators, parents, and community leaders was essential in sustaining girls' participation in STEM subjects. The findings from both Global North and South settings emphasize the importance of multi-level interventions that include community, school, and policy actors.

Higher Education and the Leaky Pipeline

Gender disparities intensify as women progress through higher education and into STEM careers. The "leaky pipeline" phenomenon refers to the progressive attrition of women at each successive educational and professional stage. Miner et al. (2018) argue that systemic norms such as expectations of constant availability and undervaluing of caregiving responsibilities create structural disadvantages for women. This is further substantiated by trend analyses showing that although more women are enrolling in STEM-related undergraduate programs, their representation declines sharply in doctoral programs and faculty leadership roles (Elmer et al., 2024). The imbalance is especially pronounced in engineering and technology disciplines. Despite women constituting the majority in some science-related master's programs, their numbers dwindle at the doctoral level and are scarcely visible in high-ranking academic or industry positions. This underrepresentation reflects a confluence of institutional, societal, and personal factors that inhibit women's career advancement.

Global and Intersectional Perspectives

Much of the existing literature has focused on gender as a binary construct and has primarily examined contexts in high-income countries. However, recent studies have emphasized the importance of adopting an intersectional lens that accounts for how gender interacts with other social categories such as ethnicity, rurality, disability, and class. Mathew et al. (2024) and Saikia (2024) underscore the importance of addressing intersecting barriers such as early marriage, lack of female role models, and inflexible work schedules in India. Similarly, in Mozambique and Uganda, community and family support were found to be crucial determinants of girls' STEM participation (Lasekan et al., 2024). These regional studies reveal the limitations of one-size-fits-all approaches and highlight the necessity of localized, culturally responsive policies and programs.

Bibliometric Approaches to Understanding Gender Parity in STEM

Bibliometric analysis has emerged as a valuable method for mapping the development of gender parity research in STEM. Ghiasi et al. (2015) analyzed authorship trends in engineering publications and revealed that women, while underrepresented, often publish in higher-impact journals. Dehdarirad (2016) expanded this work to include a broader range of STEM disciplines, identifying fragmented thematic development and low levels of international collaboration. Later studies integrated more sophisticated methodologies. Ruggieri et al. (2021) examined open-access publications and found that female researchers were likelier to publish as first authors in Gold OA journals. Thelwall and Nevill (2019) analyzed over 30 million articles and concluded that team composition significantly influences citation impact, further emphasizing structural factors in academic visibility. These studies have laid the groundwork for understanding the epistemic landscape and identifying gaps in scholarly engagement.

By mapping the intellectual structure and emerging themes in gender parity research in STEM, the current study provides a comprehensive understanding of past progress, ongoing challenges, and future directions. This bibliometric analysis addresses critical gaps in the literature, particularly the lack of longitudinal and intersectional perspectives and the limited evaluation of systemic reforms. Through bibliographic coupling and co-word analysis, the study identifies thematic clusters and research frontiers that can inform targeted, evidence-based policy interventions. Ultimately, this research supports a more inclusive and sustainable future for STEM education, ensuring that gender equity becomes embedded in both academic and professional domains.

Method

Bibliometric Analysis

This study employed a bibliometric analysis to examine gender parity in STEM education. Bibliometric analysis is a quantitative research method used to assess scholarly publications' impact, trends, and patterns of scholarly publications through statistical and computational techniques (Pritchard, 1969; Chandrakumar et al., 2024). It also facilitates the evaluation of research articles, publication metadata, and citation networks within a given field (Martinez-Garcia et al., 2023). This approach enabled a comprehensive investigation of the representation and contributions of women in STEM education over time, drawing on bibliographic data from academic databases.

Data for this bibliometric analysis were retrieved exclusively from the Scopus database, which was selected due to its comprehensive coverage, robust indexing standards, and high reliability as one of the world's largest abstract and citation repositories of peer-reviewed literature. Scopus offers extensive multidisciplinary coverage, including journals, conference proceedings, and book chapters across STEM fields, making it particularly suitable for mapping global research trends on gender parity. Its advanced analytical tools and export features also facilitate accurate bibliometric analyses, such as citation tracking, co-citation mapping, and keyword co-occurrence visualization, which are central to this study's objectives.

The analysis covered publications from 2000 to 2024 to capture both historical developments and recent advancements related to gender parity in STEM education. A comprehensive search string was developed using relevant keywords and Boolean operators, including "gender parity in STEM," "women in science and technology," "STEM education and gender," "gender gap in STEM," and "bibliometric analysis of women in STEM." These terms were selected to ensure the inclusion of diverse studies focusing on representation, equity, and participation of women in STEM. The study employed two main bibliometric techniques: co-citation analysis to identify the foundational literature shaping the field and co-word analysis to reveal emerging thematic patterns and research clusters.

The co-citation analysis identified the ten most frequently cited works that shaped the discourse on gender parity, offering insights into foundational literature. Keyword co-occurrence was used to detect recurring themes and research clusters. Co-word analysis enabled the mapping of collaborative relationships and thematic linkages across authors and institutions, revealing emerging research directions in the field (Wider et al., 2024a). This approach also allowed the identification of conceptual gaps and interconnections between topics (Zhao et al., 2024), offering a dynamic view of how research on gender parity in STEM education has evolved. In subsequent analyses, newly formed keyword clusters were tracked to uncover emerging theoretical frameworks and novel research pathways (Wider et al., 2024b).

Search String

The search string was carefully constructed to retrieve a comprehensive dataset of literature related to gender parity in STEM education and women's representation in science and technology. It combined two sets of keywords to ensure broad and relevant coverage of the topic. The first set of keywords: *"Gender Equality," "Women in STEM," "Gender Parity in Education,"* and *"Equity in Higher Education"*, targeted a wide range of gender-related studies. "Gender Equality" encompassed discussions on policies and structural efforts to address gender-based disparities. "Women in STEM" specifically focused on female participation in scientific and technological fields. "Gender Parity in Education" included literature addressing access, retention, and achievement gaps, while "Equity in Higher Education" captured systemic and institutional dimensions of gender representation. The second set of keywords: *"STEM Education," "Engineering Education," "Technology and Science Learning,"* and *"Technical Education"*, refined the search within STEM disciplines. "STEM Education" served as an overarching term for all science- and technology-related academic domains. "Engineering Education" was vital given its historically low levels of female participation. "Technology and Science Learning" broadened the scope to include teaching and learning strategies, while "Technical Education" captured literature focused on vocational and applied STEM pathways, where gender disparities are also evident. This combined search string provided a robust bibliometric analysis dataset, enabling the identification of key trends, influential works, thematic patterns, and research gaps. It also ensured that the selected literature offered a holistic understanding of the challenges, interventions, and progress in advancing women's representation in STEM education.

Results

The bibliometric analysis examined the collection of academic papers in the Scopus database with a focus on gender parity in STEM education. A total of 11,046 documents related to gender disparities in STEM were identified. As illustrated in Figure 1, the earliest publication in this area appeared in 2016, with the number of publications steadily increasing over time and peaking in 2024.

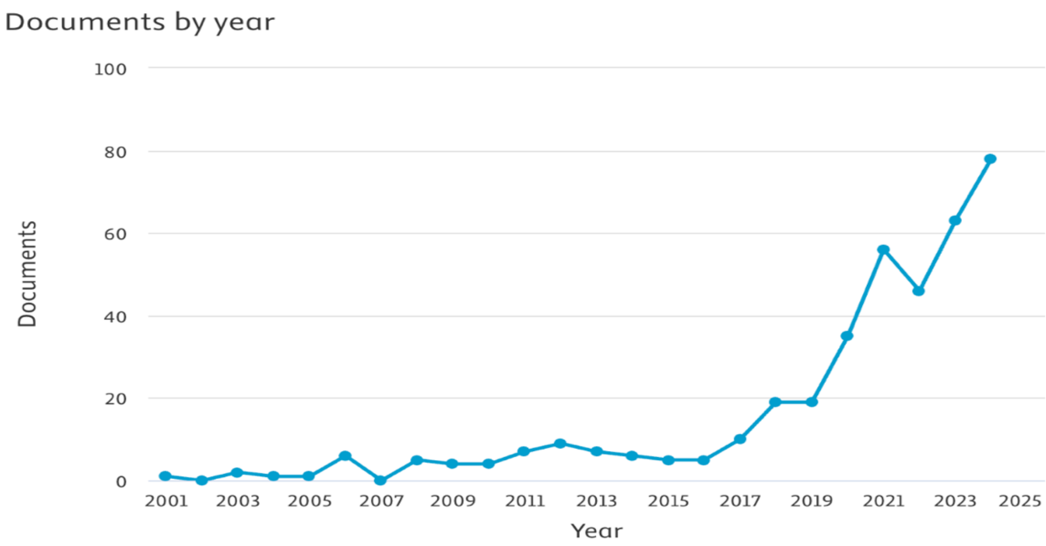

Figure 1. Annual Publications on Gender Parity in STEM Education, Scopus (2000–2024)

An average annual growth rate of approximately 25% was observed, except for an unexpected decline in 2022. The temporal distribution of publications suggests sustained scholarly interest in gender parity, except for this singular dip. This trend underscores the growing academic recognition of gender issues in STEM fields. Therefore, researchers should continue to engage with and publish in specialized journals dedicated to gender parity to advance the discourse further and maintain momentum in this critical area of study.

Co-citation Analysis

This bibliometric analysis found the co-citation analysis using the keywords. From 11,046 with 31 cited references are included, with a threshold of 4 cited references in the co-citation analysis. The top ten documents with the highest co-citation and total link strength are displayed in Table 1 based on VOSviewer v1.6.20 analysis, while the image generated on co-citation analysis is displayed in Figure 2.

Table 1. Top 10 Documents with the Highest Co-citation and Total Link Strength

No.	Documents	Citation	Total link strength
1	Cheryan, S., Ziegler, S. A., Montoya, A. K., & Jiang, L. (2017). Why are some STEM fields more gender balanced than others? *Psychological bulletin*, *143*(1), 1.	9	20
2	Diekman, A. B., Brown, E. R., Johnston, A. M., & Clark, E. K. (2010). Seeking congruity between goals and roles: A new look at why women opt out of science, technology, engineering, and mathematics careers. *Psychological Science, 21*(8), 1051–1057.	7	17
3	Dasgupta, N., & Stout, J. G. (2014). Girls and women in science, technology, engineering, and mathematics: STEMing the tide and broadening participation in STEM careers. *Policy Insights from the Behavioral and Brain Sciences, 1*(1), 21–29.	9	15
4	Stoet, G., & Geary, D. C. (2018). The gender-equality paradox in science, technology, engineering, and mathematics education. *Psychological Science, 29*(4), 581–593.	5	15
5	Fouad, N. A., Hackett, G., Smith, P. L., Kantamneni, N., Fitzpatrick, M., Haag, S., & Spencer, D. (2010). Barriers and supports for continuing in mathematics and science: Gender and educational level differences. *Journal of Vocational Behavior, 77*(3), 361–373.	4	13
6	Else-Quest, N. M., Hyde, J. S., & Linn, M. C. (2010). Cross-national patterns of gender differences in mathematics: A meta-analysis. *Psychological Bulletin, 136*(1), 103–127.	5	11
7	Lent, R. W., Brown, S. D., & Hackett, G. (1994). Toward a unifying social cognitive theory of career and academic interest, choice, and performance. *Journal of Vocational Behavior, 45*(1), 79–122.	4	11
8	Ceci, S. J., Ginther, D. K., Kahn, S., & Williams, W. M. (2014). Women in academic science: A changing landscape. *Psychological Science in the Public Interest, 15*(3), 75–141.	5	9
9	Chavatzia, T. (2017). *Cracking the code: Girls' and women's education in science, technology, engineering and mathematics (STEM).* UNESCO.	4	9
10	Organisation for Economic Co-operation and Development (OECD). (2016). *PISA 2015 results (Volume I): Excellence and equity in education.* OECD Publishing.	4	9

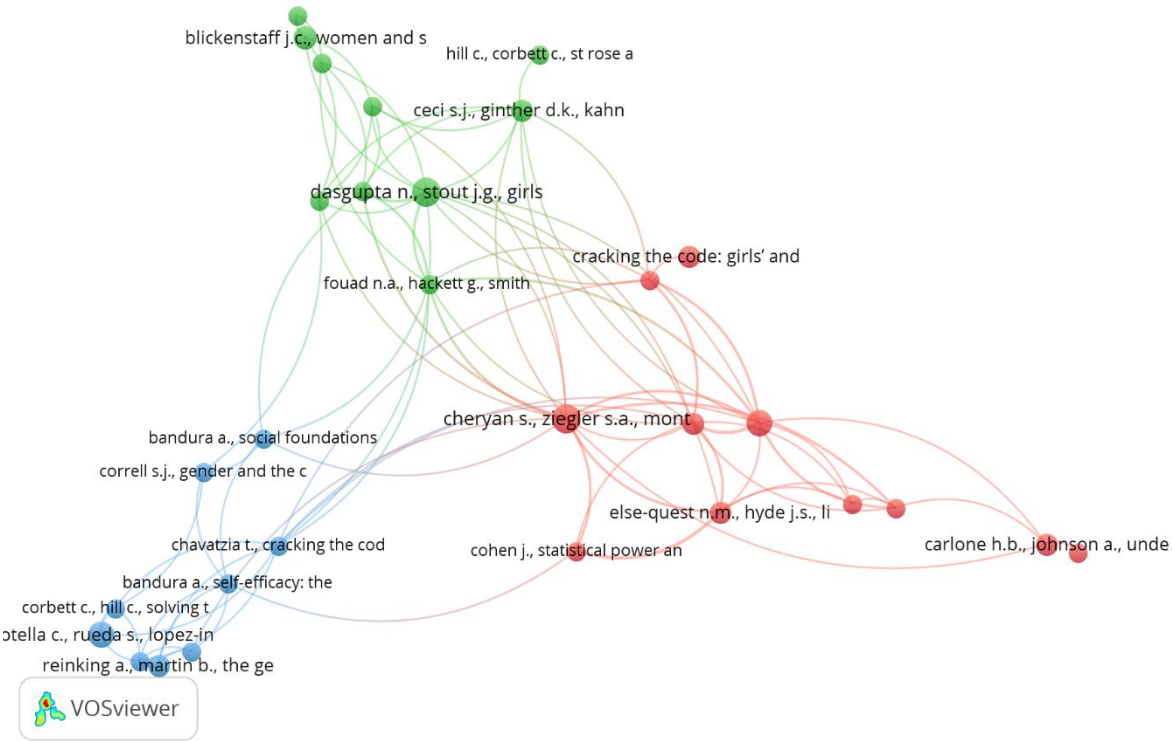

Figure 2. Co-citation Analysis of Gender Parity in STEM Education

Cluster 1: Identity Formation, Stereotypes, and Structural Barriers in Women's STEM Participation

Cluster 1 reflects a multidimensional scholarly exploration of the persistent gender gap in STEM, particularly emphasizing identity development, societal stereotypes, and institutional constraints. Carlone and Johnson (2007) offer a seminal framework on science identity, emphasizing the significance of competence, performance, and recognition in shaping the experiences of women of color in STEM. Cheryan et al. (2017) build on this by analyzing how cultural representations and environmental factors contribute to gender imbalances across specific STEM disciplines. UNESCO (2017) amplifies the discussion by documenting global systemic educational barriers that reinforce gender inequity, linking these structural issues to policy deficits. The psychological underpinnings of these disparities (Diekman et al. 2010; Else-Quest et al. 2010) address how goal incongruity and cross-national achievement patterns shape girls' aspirations. Makarova et al. (2019) delve into the internalization of gender stereotypes during secondary education, demonstrating how early exposure to biased messages narrows future STEM career interests. McGee and Bentley (2017) contribute critical insight into the paradox faced by Black women in STEM success coupled with marginalization underscoring the complexity of intersectional identities in hostile academic environments. Stoet and Geary (2018) introduce the "gender-equality paradox," suggesting that in more egalitarian societies, broader career choices may ironically widen gender gaps in STEM due to societal preferences. Su and Rounds (2015) complement this with a meta-analytic review of interest differences between people-oriented and thing-oriented careers, offering psychological explanations for occupational segregation.

Cluster 2: Structural Barriers, Role Models, and Pandemic-Era Challenges in Women's STEM Pathways

Cluster 2 captures the layered structural and psychological factors that influence women's STEM trajectories.

Recent scholarship contextualizes these dynamics within global disruptions such as the COVID-19 pandemic. Blackburn (2022) illustrates how the pandemic disproportionately impacted female STEM academics, exacerbating existing workload and visibility inequities. This builds upon the foundational metaphor of the "leaky pipeline" presented by Blickenstaff (2005), which describes the systematic attrition of women across educational and career stages in STEM. Cech et al. (2011) expand this narrative by introducing the concept of professional role confidence, showing how internalized doubts, especially among women in engineering, compromise long-term persistence. Ceci et al. (2014) offer a broad review of women's representation in academic science, revealing persistent but subtle structural barriers.

Dasgupta and Stout (2014) emphasize early interventions and environmental support as key strategies to combat these challenges. Their research underscores how positive early experiences can shift STEM trajectories meaningfully. Drury et al. (2011) dissect the influence of female role models and differentiate between their effects on recruitment versus retention, suggesting that visibility alone is insufficient without structural support. Fouad et al. (2010) highlight how institutional culture, self-efficacy, and cross-level support systems shape persistence across the academic pipeline. Hill, Corbett, and St. Rose (2010), in *Why So Few?*, synthesize much of this literature, identifying systemic educational and workforce biases that reinforce gender disparities. Lent et al.'s (1994) Social Cognitive Career Theory offers a theoretical scaffold for understanding how personal agency, learning experiences, and environmental feedback shape career development in STEM. Makarova et al. (2019) reaffirm that early exposure to gender stereotypes significantly shapes long-term STEM aspirations. Overall, this cluster underscores that while role models and personal confidence are important, they must be embedded within broader systemic reforms to effect lasting change.

Cluster 3: Psychological Constructs, Role Models, and Multi-Factorial Barriers to Girls' STEM Engagement

Cluster 3 emphasizes the psychological and sociocultural dimensions that intersect with structural challenges to influence girls' and women's engagement in STEM. Bandura's (1986) social cognitive theory introduces self-efficacy as a central mechanism through which individuals assess their capabilities, which is critical for understanding gendered differences in STEM participation. Correll (2001) furthers this by demonstrating how biased self-assessments, often influenced by societal cues, distort girls' perceptions of their STEM competence. Botella et al. (2019) underscore the multifaceted nature of STEM underrepresentation, illustrating how institutional, cultural, and psychological factors interact to deter women's participation. Chavatzia (2017), through UNESCO's *Cracking the Code* report, maps global disparities in STEM education and calls for data-driven policy responses. Corbett and Hill (2015) identify the predictors of success for women in engineering and computing, including early exposure, confidence-building strategies, and supportive learning environments. Dasgupta and Stout (2014) also advocate for positive counter-stereotypical experiences to offset negative messaging, reinforcing the necessity of sustained exposure to inclusive STEM practices. González-Pérez et al. (2020) examine how the presence of visible female role models elevates aspirations and reinforces girls' belief in their STEM potential. Reinking and Martin (2018) build on these insights by offering frameworks grounded in grassroots activism and contemporary theory to sustain girls' interest from early education through to tertiary pathways.

Table 2. Co-citation Clusters of Gender Parity in STEM Education

Cluster	Cluster label	No. of articles	Representative publications
1 (red)	Identity Formation, Stereotypes, and Structural Barriers in Women's STEM Participation	11	Carlone and Johnson (2007), McGee and Bentley (2017), Diekman et al. (2010), Su and Rounds (2015), Cheryan et al. (2017), Stoet and Geary (2018), Else-Quest, Hyde, and Linn (2010), Makarova, Aeschlimann, and Herzog (2019).
2 (Green)	Structural Barriers, Role Models, and Pandemic-Era Challenges in Women's STEM Pathways	10	Blackburn (2022), Blickenstaff (2005), Cech et al. (2011), Fouad et al. (2010), Ceci et al. (2014), Hill et al. (2010), Lent, Brown, and Hackett (1994), Makarova et al. (2019), Drury et al. (2011).
3 (Blue)	Psychological Constructs, Role Models, and Multi-Factorial Barriers to Girls' STEM Engagement	9	Bandura's (1986, 1997), Bandura's framework, Correll (2001), Botella et al. (2019), Chavatzia (2017), Dasgupta & Stout (2014), González-Pérez, Mateos de Cabo, & Sáinz (2020), Reinking & Martin (2018), Corbett & Hill (2015).

Co-word Analysis

A co-word analysis was conducted on 1,895 keywords to identify key themes in literature on gender parity in STEM education (see Table 3).

Table 3. Top 15 Keywords in the Co-occurrence of Keywords Analysis

Rank	Keyword	Occurrences	Total link strength
1.	Engineering education	205	1047
2.	students	113	691
3.	professional aspects	115	680
4.	gender equality	99	437
5.	stem	66	315
6.	stem (science, technology, engineering, and mathematics)	48	293
7.	higher education	46	287
8.	science technologies	41	273
9.	education computing	47	265
10.	women in stem	47	242
11.	engineering and mathematics	31	214
12.	high educations	28	206
13.	gender	41	192
14.	women in science	25	190
15.	education	37	181

By applying a minimum occurrence threshold through multiple trials, 45 keywords were selected, forming four thematic clusters. The most frequent terms were “engineering education” (205), “students” (113), and “professional aspects” (115), highlighting a focus on education, student experiences, and career development. This thresholding ensured a meaningful network visualization that reflects dominant research areas and conceptual structures related to women’s representation in science and technology. The analysis supports deeper exploration of emerging trends and thematic directions in the field.

The span of the web of co-word analysis of this bibliometric analysis based on VOS viewer analysis generated three clusters of keywords based on co-occurrence. Consequently, the network structure of the keywords co-occurrence is visualized in Figure 3. There are 3 identifiable clusters. It can be deduced that all are closely related. The following is further discussed and elaborated based on each cluster.

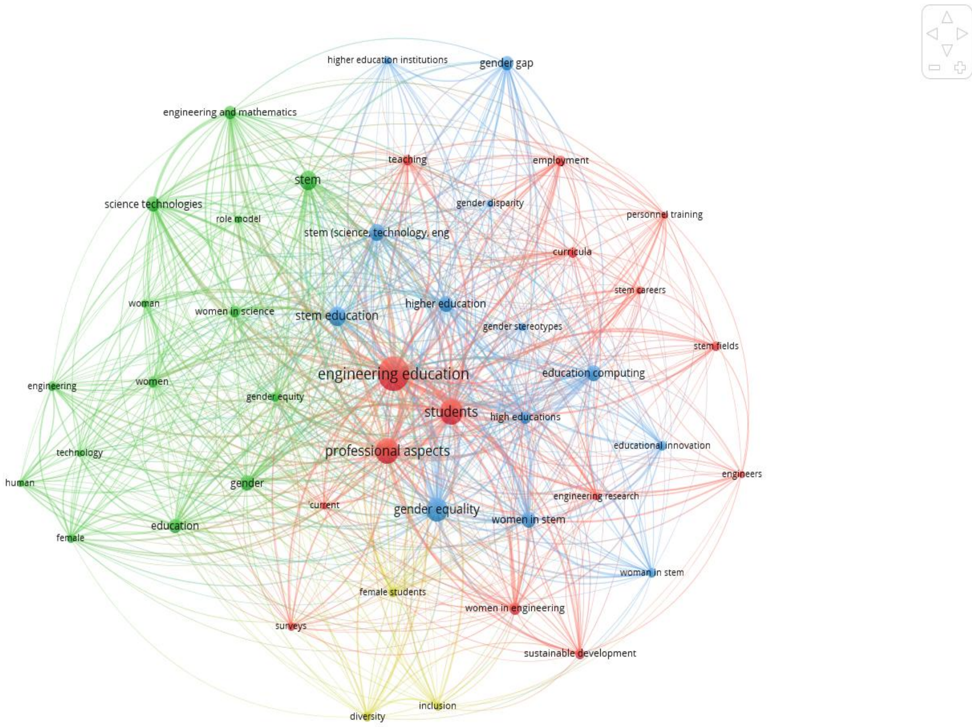

Figure 3. Co-occurrence Analysis of Gender Parity in STEM Education

Cluster 1: Advancing Diversity and Inclusion in STEM Education and Careers

Cluster 1 explores current efforts and challenges in promoting diversity and inclusion within STEM education, with a particular focus on engineering programs and professional pathways. A consistent theme across these studies is the persistent underrepresentation of women and other marginalized groups in STEM fields despite incremental improvements in access and participation (Popo-Olaniyan et al., 2022). While gender-inclusive curricula and institutional diversity policies have gained traction, structural barriers such as gendered career expectations, inequitable mentorship access, and employment discrimination continue to impede equitable outcomes (Schmader, 2022). Notably, engineering education plays a pivotal role in shaping future STEM professionals. Although female participation has increased through targeted reforms such as curriculum redesign, mentorship initiatives, and visibility campaigns, retention in STEM careers remains limited. Research highlights that women are disproportionately affected by workplace biases, lack of leadership representation, and constrained professional development opportunities (Ryan et al., 2021). As such, personnel training and career support mechanisms are recognized as critical levers for sustaining engagement (Borger, 2025). Emerging trends in this cluster point toward the importance of fostering inclusive learning environments and expanding access to hands-on research and leadership development opportunities (Saxe et al., 2024). Recent empirical studies and surveys have been instrumental in identifying persistent policy and practice gaps, offering actionable insights for designing evidence-based interventions (Reggiani et al., 2024).

Cluster 2: Bridging Gender Gaps through STEM Education, Representation, and Policy

Cluster 2 interrogates the intersection of STEM education, gender representation, and policy reform as central components in advancing gender equity. The literature highlights how pedagogical practices, especially in mathematics and engineering, often reflect and reproduce existing inequalities, despite efforts to promote access (ElMorally et al., 2022). Initiatives have expanded globally, yet gender disparities remain entrenched, shaped by both explicit and implicit biases in educational content, institutional culture, and broader sociocultural norms (Peixoto et al., 2018). A prominent subtheme is the transformative role of female representation in challenging stereotype threats and fostering resilience among aspiring women in STEM. Role models are shown to influence career aspirations, increase academic motivation, and mitigate psychological barriers to entry and persistence (Nweje et al., 2025). Beyond representation, the literature points to deeper societal issues, such as gender norms, cultural expectations, and intersectional disadvantages that require structural redress (Breen, 2021). Emerging from this cluster is a strong consensus that achieving gender parity requires more than isolated initiatives. Instead, a systemic shift is necessary, characterized by inclusive pedagogies, gender-responsive curricula, institutional reforms, and sustained policy commitments (Cobian et al., 2024). There is growing recognition of intersectionality as a research and practice frontier, particularly regarding the compounded marginalization faced by women of color, LGBTQ+ individuals, and persons with disabilities in STEM (Kim, 2019).

Cluster 3: Challenging Gender Disparities through Innovation in STEM Higher Education

Cluster 3 focuses on higher education as a pivotal context for addressing persistent gender disparities in STEM fields. Central to this cluster is the recognition that, despite increased female enrollment in some STEM disciplines, significant gaps remain, particularly in computing, engineering, and mathematics (Leong, 2023). These disparities are often reinforced by stereotype threats, lack of belonging, and implicit biases embedded in academic environments (Schmader, 2022). Educational innovation is identified as a critical pathway for disrupting these entrenched inequalities. Studies within this cluster emphasize the impact of learner-centered approaches such as project-based learning, flipped classrooms, and collaborative teaching models in mitigating gendered assumptions and creating more inclusive academic cultures (Moore et al., 2020). Higher education institutions are portrayed as both barriers and catalysts for change: their policies, pedagogical frameworks, and leadership structures determine whether gender disparities are perpetuated or dismantled. Recent literature in this cluster also reveals a growing emphasis on the role of computing education in the digital economy, where female underrepresentation remains stark (Ryan et al., 2021). Policy interventions aimed at scholarship provision, representation in academic leadership, and inclusive recruitment practices are emerging as key strategies for driving transformation (Borger, 2025). The trend toward institutional accountability and the demand for gender-sensitive educational innovation suggest that future research and reform efforts will likely center on systemic redesign, equity audits, and intersectional inclusion in higher education (Boyle et al., 2021). The resulting clusters are summarized in Table 4, which presents the thematic groupings, number of keywords per cluster, and representative keywords reflecting dominant areas of research focus on gender parity in STEM education.

Table 4. Co-word Analysis on Gender Parity in STEM Education

Cluster No and color	Cluster label	Number of keywords	Representative Keywords
1 (red)	Advancing Diversity and Inclusion in STEM Education and Careers	18	Curricula, diversity, employment, engineering education, engineering research, female students, inclusion, personnel training, professional aspects, stem careers, stem fields, students, surveys.
2 (green)	Bridging Gender Gaps through STEM Education, Representation, and Policy	14	education, engineering, engineering and mathematics, female, gender, gender equity, human, role model, science technologies, stem, technology, woman, women, women in science
3 (blue)	Challenging Gender Disparities through Innovation in STEM Higher Education	3	education computing, educational innovation, gender disparity, gender equality, gender gap, gender stereotypes, higher education institutions, stem (science, technology, engineering, mathematics), stem education, woman in stem.

Discussion

This study aimed to map the intellectual structure and forecast emerging research trajectories on gender parity in STEM education through bibliometric analysis using co-citation and co-word techniques. The findings strongly support the initial assumption that while meaningful progress has been achieved in expanding women's participation in STEM fields, significant structural, psychological, and sociocultural barriers continue to persist across educational and professional pathways. The steady growth of scholarly interest in this area, which peaked in 2023, reflects sustained global efforts to address gender inequities in science and technology education. The temporary decline observed in 2022 may indicate shifting research priorities or the integration of gender-focused inquiries into broader interdisciplinary studies, while the resurgence in 2023 suggests renewed academic and policy-driven momentum, likely influenced by post-pandemic priorities related to equity and sustainable development.

The co-citation analysis revealed three major thematic clusters that capture the field's intellectual landscape. The first cluster, centered on identity formation, stereotypes, and structural barriers, emphasizes the critical influence of early socialization, internalized bias, and institutional norms on female participation in STEM (Carlone & Johnson, 2007; Cheryan et al., 2017; Makarova et al., 2019). These findings underscore that gender disparities are not simply the result of individual choices but are deeply embedded in systemic practices that perpetuate exclusionary norms and limit opportunities for women (UNESCO, 2017). The second cluster, which focuses on structural barriers, role models, and pandemic-era challenges, illustrates how institutional culture, professional confidence, and external disruptions intersect to shape women's academic and career trajectories (Blackburn, 2022; Blickenstaff, 2005). It further shows that while visibility and representation through role models are essential, they must be complemented by structural reforms, inclusive policies, and supportive institutional environments to bring about lasting change (Drury et al., 2011; Hill et al., 2010). The third cluster highlights psychological constructs and multifactorial barriers, such as self-efficacy, stereotype threat, and belongingness, which are especially critical during adolescence and higher education when career intentions are formed and gender-based attrition becomes more pronounced (Bandura, 1997; Correll, 2001; González-Pérez et al., 2020).

The co-word analysis complements these findings by identifying emerging research trajectories and highlighting thematic convergence around inclusive curricula, gender-sensitive pedagogy, and institutional transformation. Recurring terms such as "engineering education," "women in STEM," "gender equality," and "educational innovation" reflect a research field that is increasingly oriented toward systemic inclusivity and pedagogical reform. Together, these findings not only provide a historical overview of the field but also identify actionable research directions that can guide future scholarly inquiry and inform policy and practice.

Implications

The implications of this study are significant for both research and practice. From a research perspective, the findings highlight the need for deeper, more nuanced investigations into gender equity in STEM. Future studies should prioritize longitudinal research to examine the long-term effectiveness of interventions, intersectional analyses to understand how gender interacts with other identities such as race, class, disability, and geography (Crenshaw, 1991; Mathew et al., 2025; Saikia, 2024), and comparative policy evaluations to assess the impact of systemic reforms across diverse contexts. Mixed-method approaches that integrate bibliometric analyses with qualitative evidence could enrich our understanding of lived experiences, institutional practices, and policy outcomes. Furthermore, examining the influence of emerging technologies—such as artificial intelligence, virtual learning environments, and gamified interventions—on female participation in STEM represents a promising direction for future research (Zhu & Liu, 2020; Chen et al., 2018). Collaborative, cross-national research that compares sociocultural and policy variables across regions can also provide valuable insights into how context shapes gender representation in STEM (Lasekan et al., 2024; El Nagdi & Roehrig, 2019).

From a practical standpoint, the results underscore the need for systemic, multi-level interventions that span educational, institutional, and industrial settings. Schools and universities should adopt gender-inclusive curricula that highlight women's contributions to science and technology, challenge biased narratives, and integrate diverse pedagogical approaches (Cheryan et al., 2017; Corbett & Hill, 2015). Teacher training programs must be strengthened to address unconscious biases and equip educators with strategies to foster inclusive classroom environments that enhance girls' self-efficacy and sense of belonging (Stephenson et al., 2022; Moss-Racusin et al., 2018). Structured mentorship and sponsorship programs that connect female students with successful women in STEM should be institutionalized to improve retention, confidence, and career readiness (González-Pérez et al., 2020; Drury et al., 2011). Institutions must also strengthen accountability mechanisms through gender equity audits, diversity benchmarks, and annual reporting, linking these measures to funding, accreditation, and promotion processes to embed equity into organizational culture (European Commission, 2019; OECD, 2021). Policymakers should develop targeted outreach programs—particularly in rural and underserved areas—to ensure equitable access to STEM education from an early age (Bussey & Bandura, 1999; Dasgupta & Stout, 2014), while also incentivizing inclusive recruitment practices, flexible work arrangements, and parental support policies to support women's career progression (Ceci et al., 2014; Blackburn, 2022).

The private sector has a crucial role to play as well. Industry leaders should set clear diversity goals, design inclusive innovation ecosystems, and create flexible career pathways to attract and retain women in STEM careers (McKinsey & Company, 2022). Gender equity should be viewed not only as a social responsibility but also as a strategic advantage that drives innovation and competitiveness in the global knowledge economy. Additionally, leveraging digital technologies such as AI-powered learning platforms, online mentorship networks, and virtual laboratories can help overcome geographic and financial barriers, democratizing access to STEM education and career development opportunities (Zhu & Liu, 2020; Chen et al., 2018). These innovations should be integrated into national education policies to ensure scalability, accessibility, and long-term impact.

Overall, this study not only enriches the scholarly understanding of gender parity in STEM but also provides actionable insights that can guide the design of policies, institutional practices, and future research. By integrating these research and practice implications, stakeholders across academia, government, and industry can work collaboratively to create more inclusive and equitable STEM ecosystems. Such collective action is essential to closing gender gaps, advancing innovation, and ensuring that women's voices, talents, and leadership are fully represented in shaping the future of science and technology.

Conclusion

Gender parity in STEM education continues to be an unresolved and pressing global issue. Despite decades of policy attention and educational reform, the underrepresentation of women in key STEM fields, especially engineering, computing, and leadership roles, persists. This systemic inequity constrains global innovation potential, reinforces labor market segmentation, and obstructs efforts to achieve the Sustainable Development Goals (UNESCO, 2025a; UN Women, 2020).

This bibliometric analysis synthesized data from 585 Scopus-indexed publications from 2000 to 2024. Through co-citation and co-word analyses, the study identified three intellectual clusters: identity formation and stereotypes, structural and psychological barriers, and innovation-driven pathways in higher education. Key themes such as representation, role models, early intervention, educational innovation, and policy reform were consistently emphasized. Notably, the results indicate that while the research field has matured intellectually, it remains limited in terms of intersectional analysis, geographic diversity, and interdisciplinary integration. The findings have broad implications. Theoretically, they validate the significance of feminist theory (Harding, 1986) and intersectionality (Crenshaw, 1991) in explaining and responding to gender inequities in STEM. Practically, the results inform actionable strategies across the educational, institutional, and industrial sectors, such as embedding inclusive pedagogy, institutionalizing mentorship, and expanding virtual access to STEM resources. These interventions are feasible and necessary for fostering equitable and resilient STEM ecosystems.

However, several limitations should be acknowledged. First, the reliance on the Scopus database may have excluded non-English, regional, or emerging literature, thus narrowing the scope of insights. Second, while useful for mapping trends, bibliometric indicators do not account for the qualitative depth, contextual effectiveness, or real-world impact of studies. Third, the current analysis provides a snapshot of the academic discourse but cannot assess the translation of research findings into policy or practice. To address these limitations, future research should incorporate data from multiple databases (e.g., Web of Science, ERIC), include non-traditional publication sources, and triangulate bibliometric findings with qualitative or case-based evidence. Longitudinal studies should examine the effectiveness of specific interventions over time. Emerging technologies such as virtual reality, AI, and gamified learning should also be assessed in improving girls' STEM engagement and retention.

In conclusion, gender parity in STEM education is not merely a question of access. It is a matter of justice, innovation, and global competitiveness. The challenges are entrenched but not insurmountable. The results of this study suggest that a shift toward holistic, intersectional, and systems-level reform is urgent and achievable. Collaborative leadership from governments, educators, researchers, industries, and communities will be essential to closing the gender gap. Moving forward, a gender-balanced STEM ecosystem will be indispensable for achieving equity and addressing the complex challenges of the 21st century, from climate change to digital transformation. By centering women's voices, capabilities, and aspirations in science and technology, we pave the way for a more inclusive and sustainable future.

Recommendation

Building on the study's findings and implications, several strategic recommendations are proposed to advance gender parity in STEM education and careers. First, teacher education institutions and schools should institutionalize comprehensive teacher-training programs grounded in Universal Design for Learning (UDL) framework with a strong emphasis on gender-responsive pedagogy. Such a program should equip educators with the knowledge, strategies, and tools to design inclusive learning environments that address diverse learner needs while actively dismantling gender biases and stereotypes in STEM education. Through UDL's core principles, which include multiple means of engagement, representation, and action and expression, teachers can cultivate classroom practices that promote equity, belongingness, and participation for all learners, particularly girls and women. The training should include modules on bias awareness, stereotype threat mitigation, inclusive curriculum design, and the integration of real-world female STEM contributions into instruction. Moreover, practicum-based components, mentoring initiatives, and micro-credentialing can further ensure the effective translation of gender-responsive principles into classroom practice. This targeted investment in teacher capacity-building is essential for fostering inclusive pedagogical approaches, increasing women's participation and retention in STEM fields, and supporting broader efforts toward equity and social justice in education.

Second, curriculum reforms should be undertaken to integrate gender perspectives into STEM content. This includes highlighting the contributions of women scientists and engineers, revising examples and case studies to challenge stereotypes, and ensuring that learning materials reflect diverse identities and experiences. Such inclusive curricular approaches can reshape student perceptions and encourage more girls to pursue STEM pathways. Third, structured mentorship and sponsorship programs must be institutionalized across schools and universities. By connecting female students with successful women professionals and researchers, these initiatives can provide vital role models, support networks, and career guidance that improve retention and advancement in STEM fields. Fourth, institutional accountability mechanisms should be strengthened through regular gender equity audits, transparent diversity reporting, and linking funding or accreditation to progress on inclusion benchmarks. Policies supporting flexible work arrangements, parental leave, and career re-entry pathways can further address systemic barriers to women's progression in academia and industry.

Fifth, policy interventions and government support are crucial. Policymakers should prioritize targeted scholarship programs, outreach initiatives in underserved communities, and national campaigns promoting girls' participation in STEM. Data systems should also track participation, completion, and leadership metrics disaggregated by gender to inform evidence-based policymaking. Finally, leveraging digital and AI-driven platforms can expand access to quality STEM learning opportunities, particularly for marginalized groups. Virtual labs, online mentorship networks, and AI-powered adaptive learning tools can bridge geographic and socioeconomic gaps while supporting personalized and equitable learning experiences. Together, these multi-level recommendations, spanning teacher training, curriculum design, mentorship, institutional reform, policy, and technology integration, can create a more inclusive STEM ecosystem. They will help increase women's participation, retention, and leadership in science and technology, while advancing broader goals of equity, innovation, and sustainable development.

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