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Women in STEM Education Research, 2006-2025: Knowledge Evolution, Global Collaboration, and SDG Alignment

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Abstract

This bibliometric study maps the development of research on women in STEM education using 348 Scopus-indexed, English-language, open-access publications spanning 2006-2025. Bibliographic records were retrieved on June 12, 2025, and analyzed using Biblioshiny through performance analysis, keyword co-occurrence, co-authorship, co-citation, thematic mapping, and historiographic analysis. The field recorded an annual growth rate of 14.45%, with publication output increasing markedly after 2015 and remaining high after 2020. PLOS ONE was the most productive source, followed by CBE-Life Sciences Education and Sustainability, while highly cited publications by Stoet and Geary and Dennehy and Dasgupta formed important intellectual foundations for research on gender disparities, mentoring, and institutional intervention. Collaboration was extensive: 313 of the 348 documents (89.9%) were multi-authored, and 97.8% of authors contributed to co-authored publications. However, 76% of the scholarly output originated from the Global North, indicating persistent geographical imbalance. Conceptual mapping identified a pedagogical cluster centered on education, gender, students, mathematics, and engineering, alongside a demographic and indexing cluster dominated by female, male, human, and adult. The analysis also revealed limited attention to technology education, intersectional perspectives, and Global South contexts. Overall, the literature is substantively aligned with SDGs 4 and 5 through its focus on equitable access, participation, retention, and institutional inclusion. The findings support more reciprocal North-South partnerships, context-sensitive intervention studies, and stronger integration of intersectional and technology-focused research.

Keywords: Women in STEM; Gender Equity; Bibliometric Analysis; STEM Education; SDG 4; SDG 5; Research Collaboration

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INTRODUCTION

Women's participation in Science, Technology, Engineering, and Mathematics (STEM) is essential to innovation, sustainable economic development, and social equity (Palomino-Monteza et al., 2023). Nevertheless, substantial gender disparities persist across STEM disciplines. Women account for approximately 35% of scientists globally, while their representation remains particularly limited in engineering and other traditionally male-dominated fields (Ara, 2021). For example, women received only 20.9% of engineering bachelor's degrees in 2016 (Zurn-Birkhimer et al., 2018). These disparities are not produced by a single factor. They develop through interconnected educational and institutional conditions, including gender stereotypes, curricular biases, limited access to role models, unequal classroom participation, and learning environments that do not consistently support women's STEM identity from primary through tertiary education (Afshari et al., 2024; Edosomwan et al., 2025).

Research has increasingly examined educational strategies intended to improve women's access, participation, persistence, and advancement in STEM. These strategies include mentoring, inclusive pedagogy, institutional reform, identity-supportive learning environments, and early interventions designed to challenge gender stereotypes. However, the resulting literature remains dispersed across education, psychology, sociology, public policy, and individual STEM disciplines. Consequently, the overall development of the field, its dominant themes, influential knowledge bases, and emerging research priorities have not yet been fully integrated within a single analytical framework (Ro et al., 2021; Xu et al., 2025).

The volume of research on women in STEM education has also increased substantially over the past decade. Preliminary Scopus screening conducted for this study indicated a marked expansion in publication activity, creating a body of literature that is increasingly difficult to synthesize through conventional narrative review alone. Individual studies have provided valuable evidence on women's STEM engagement, classroom participation, belonging, and peer evaluation (Clark et al., 2016; Grunspan et al., 2016). However, these studies do not reveal the broader structure of the research field, including how publication output, citation influence, thematic relationships, and international collaboration have evolved over time.

Previous reviews have mapped broad trends in STEM education, bibliometric evidence on gender disparities in science, and international perspectives on gender equity in higher education (Halevi, 2019; Khalil et al., 2024; Ro et al., 2021). Although these studies provide important foundations, they do not specifically trace the long-term development of research focused on women's educational pathways and experiences in STEM. They also provide limited integration of two dimensions that are central to equity-oriented scholarship. The first is the relationship between the literature and the Sustainable Development Goals, particularly SDG 4 on Quality Education and SDG 5 on Gender Equality. The second is the geographical distribution of knowledge production and collaboration between the Global North and Global South.

These dimensions are important because women in STEM education research operates across multiple disciplinary, institutional, and geopolitical contexts. Interdisciplinary connections among education, psychology, organizational studies, and public policy influence how gender inequalities are defined and addressed (Hughes et al., 2022). At the same time, differences in research funding, institutional capacity, publication visibility, and educational priorities may shape the themes emphasized in Global North and Global South scholarship (Hulus, 2025). Temporal changes are also relevant because the adoption of the Sustainable Development Goals in 2015 provided a stronger international framework for addressing inclusive education and gender equality (Ro et al., 2021). However, publication growth during the post-2015 period should be interpreted as temporally associated with the SDG era rather than as direct evidence that the SDGs caused the expansion of the field.

Bibliometric analysis offers an appropriate approach for examining these developments. It enables the systematic assessment of publication growth, influential authors and documents, leading sources, thematic relationships, intellectual foundations, and international collaboration patterns. Science-mapping techniques can further identify clusters of related concepts, frequently co-cited knowledge bases, and direct citation pathways through which the field has developed (Donthu et al., 2021). This approach is therefore well suited to consolidating a large and multidisciplinary body of evidence while preserving the relationships among its conceptual, intellectual, and social structures.

The present study extends prior work through an integrated dual-lens framework. The first lens examines how the literature aligns with SDG 4 and SDG 5 through its attention to equitable educational access, participation, retention, empowerment, and institutional inclusion. The second lens examines geographical patterns in productivity and collaboration through a Global North-Global South classification. Together, these perspectives allow the analysis to move beyond a descriptive account of publication output and consider whether the field's knowledge production is geographically balanced and responsive to global equity priorities.

This integrated analysis also has practical and theoretical relevance. From a practical perspective, bibliometric findings can identify areas in which educational research and policy attention are concentrated or lacking, including mentoring, inclusive pedagogy, vocational STEM education, and the representation of women role models (Bustamante-Mora et al., 2025; Halevi, 2019; Pandey & Pandey, 2024). These findings can support more informed decisions about curriculum development, institutional programming, research funding, and international collaboration. From a theoretical perspective, the analysis can reveal how frameworks related to identity, self-efficacy, belonging, stereotypes, institutional inequality, and intersectionality are positioned within the field. It can also show whether the literature has shifted from concerns about access toward questions of retention, participation, advancement, and leadership.

Several gaps justify this investigation. Educational interventions are often studied within individual institutions or national contexts without sufficient comparison across regions (Rodríguez et al., 2023; Tricco et al., 2023). Intersectional perspectives that consider the combined effects of gender, race, ethnicity, socioeconomic status, disability, and geography also remain underrepresented (Tricco et al., 2023). Methodologically, there is a need for a multi-decadal bibliometric study that combines performance analysis, science mapping, SDG alignment, and geographical equity analysis within a single design (Donthu et al., 2021; John et al., 2024).

Accordingly, this study systematically maps the development of women in STEM education research from 2006 to 2025. It examines publication and citation patterns, identifies influential authors, documents, and sources, maps conceptual and intellectual structures, and evaluates international collaboration. It also assesses the literature's alignment with SDGs 4 and 5 and examines the geographical distribution of knowledge production between the Global North and Global South. Through this approach, the study identifies established research concentrations, underrepresented themes, and priorities for more inclusive and context-sensitive STEM education research. The study addresses the following research questions:

1. How did the thematic trajectories and conceptual structure of women in STEM education research develop between 2006 and 2025?
2. What productivity, citation-impact, authorship, and source-distribution patterns characterize the scientific literature on women in STEM education?
3. How are the conceptual structure, intellectual foundations, and international collaboration patterns of the field organized?
4. How does women in STEM education research align with SDGs 4 and 5, particularly in relation to knowledge-production patterns, geographical representation, policy relevance, and intersectional inequities?

METHOD

Research Design and Study Scope

This study employed a bibliometric approach to identify and map the development of research on women in STEM education. Bibliometric analysis was selected because it enables the systematic examination of publication trends, citation impact, influential contributors, conceptual structures, intellectual foundations, and collaboration patterns within a defined body of literature (Aleixandre-Benavent et al., 2017). The search covered publications issued between 2005 and 2025; however, the earliest publication meeting the inclusion criteria was published in 2006. Accordingly, the final analytical corpus spans 2006-2025.

Data Source and Search Strategy

Bibliographic data were retrieved from the Scopus database on June 12, 2025. Scopus was selected because it provides structured bibliographic metadata suitable for performance analysis and science mapping. Because the search was conducted before the end of 2025, records from that year represent only a partial publication period.

To obtain a sufficiently broad set of potentially relevant records, the search was conducted in the title, abstract, and keyword fields using the following Boolean query:

TITLE-ABS-KEY (("women" OR "female" OR "girl*") AND ("STEM education" OR "science education" OR "technology education" OR "engineering education" OR "mathematics education"))*

The search combined population-related terms with discipline-specific education terms to capture publications addressing women and girls across science, technology, engineering, mathematics, and broader STEM educational contexts. The initial search retrieved 2,937 records.

Eligibility Criteria and Filtering Process

The initial records were refined through a sequential filtering procedure. First, the publication period was limited to 2005-2025, reducing the dataset to 2,802 records. Second, the document-type filter was applied to retain articles, reviews, and conference proceedings, resulting in 1,487 records. Third, the thematic focus was strengthened by requiring the presence of core metadata terms, including “female,” “education,” “students,” “gender,” and “STEM,” which reduced the corpus to 698 records.

The dataset was subsequently restricted to English-language publications, leaving 676 records. Finally, the open-access filter was applied, producing a corpus of 348 documents. The use of the English-language and open-access filters increased the accessibility and comparability of the records but may have excluded relevant scholarship published in other languages or behind subscription barriers.

Figure 1 summarizes the complete search, filtering, and validation process used to construct the final bibliometric corpus.

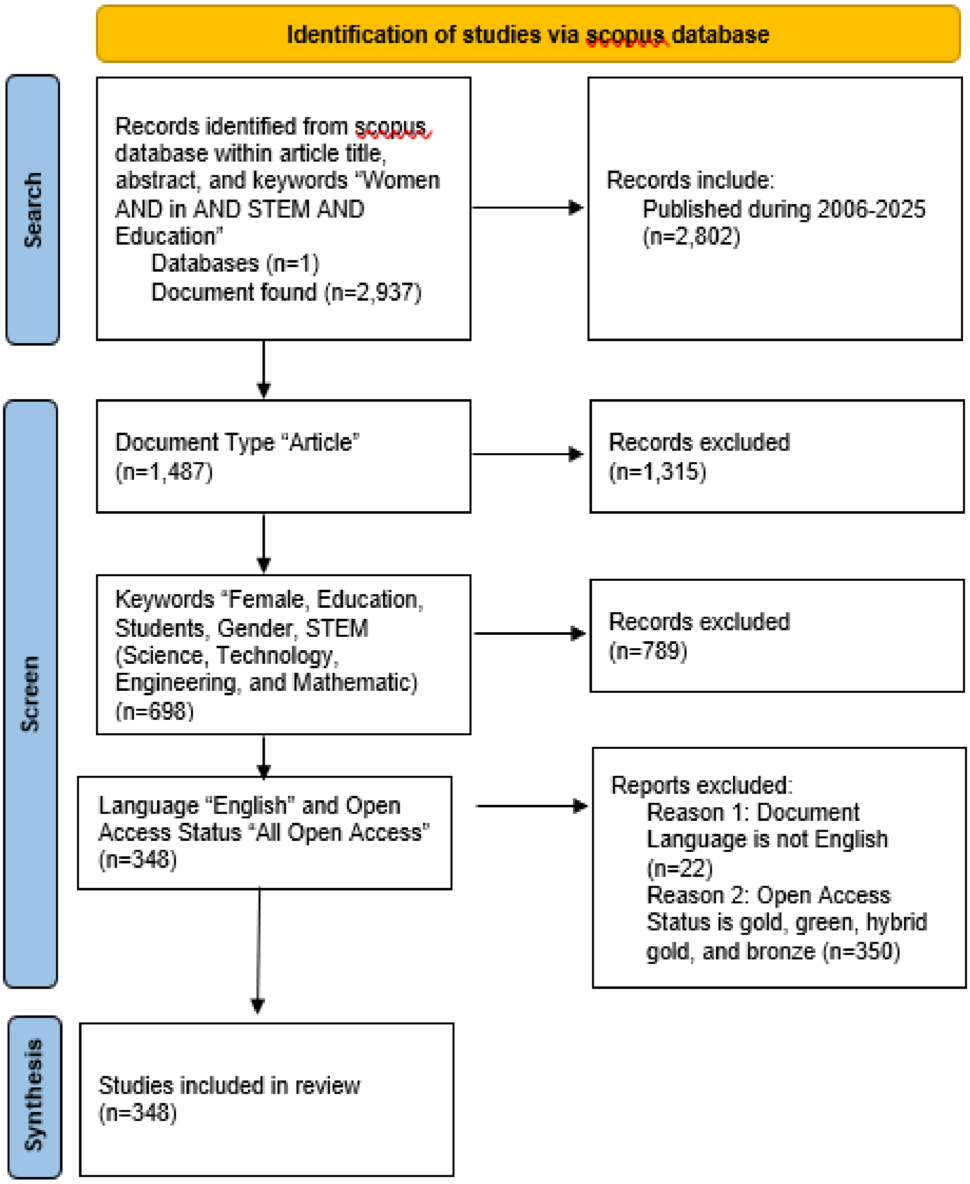

Figure 1. Bibliometric Analysis Workflow

As shown in Figure 1, the study progressed from broad Scopus retrieval to successive filtering by publication period, document type, thematic relevance, language, and open-access status. The resulting 348 records were then subjected to manual validation before bibliometric analysis.

Screening and Data Validation

A two-stage validation procedure was conducted to strengthen the thematic relevance and analytical consistency of the dataset. In the first stage, publication titles were screened systematically using Microsoft Excel. In the second stage, abstracts were reviewed against the predefined inclusion and exclusion criteria to confirm that each record addressed women or girls within a STEM education context.

The validation process was designed to identify records that satisfied the database filters but were not substantively relevant to the research questions. Following title and abstract screening, the final corpus comprised 348 documents. This procedure strengthened the reliability and thematic relevance of the dataset without claiming that database-based screening could eliminate every possible classification error.

Data Preparation and Bibliometric Software

The bibliographic records were exported from Scopus in CSV format and initially processed in Microsoft Excel. The exported metadata included document titles, authors, affiliations, corresponding-author countries, publication sources, cited references, author keywords, and indexed keywords. These data were reviewed for consistency before being imported into Biblioshiny, the web-based interface of the bibliometrix R package.

Biblioshiny was used to conduct both bibliometric performance analysis and science mapping. The software supported the examination of annual publication growth, citation impact, leading authors, influential publications, publication sources, international collaboration, keyword co-occurrence, co-citation relationships, thematic patterns, and historical citation links. Its standardized computational procedures also supported the reproducibility and comparability of the analyses.

Bibliometric Performance Analysis

Quantitative bibliometric techniques were used to assess the productivity and influence of the research field. The performance analysis identified annual publication output, the overall annual growth rate, prolific authors, highly cited documents, leading publication sources, productive countries, and collaboration indicators within the women in STEM education literature (Madudova & Corejova, 2024).

Citation-based indicators included total citations, average citations per document, citations per year, h-index, g-index, and m-index where available. Fractionalized article counts were used to distribute publication credit across co-authors. These counts were interpreted as adjusted productivity indicators rather than evidence of author order, intellectual leadership, or specific contribution roles.

Science-Mapping and Network Analysis

Science-mapping techniques were employed to examine the conceptual, intellectual, and social structures of the field. Keyword co-occurrence analysis was used to identify frequently connected concepts and thematic groupings. Co-authorship analysis mapped collaboration among countries, while co-citation analysis identified references that were frequently cited together and therefore represented related intellectual foundations.

Frequency and betweenness indicators were used to evaluate the prominence and bridging roles of terms or network entities. Frequency reflects how often a term or entity appeared, whereas betweenness indicates the extent to which it connected otherwise separate parts of a network. These measures supported the identification of central concepts and relationships within the knowledge structure (Havrlant & Kreinovich, 2017). Keyword co-occurrence and cluster analysis also enabled the assessment of terminological prevalence and conceptual relationships across the corpus (Liu & Prajapati, 2022). Table 1 presents the units of analysis, normalization procedures, minimum thresholds, clustering algorithms, and visualization settings used for each network analysis.

Table 1. Network Analysis Parameters in Biblioshiny

Network Type	Unit of Analysis	Normalization or Counting Method	Minimum Frequency/Edges	Clustering Algorithm	Layout
Keyword Co-occurrence	Author Keywords	Association Strength	5 occurrences	Louvain	Biblioshiny
Co-authorship (Country)	Countries	Fractional Counting	1 collaboration	Louvain	Biblioshiny
Co-citation	Cited References	Cosine Normalization	20 citations	Louvain	Biblioshiny
Thematic Map	Keywords	None	5 occurrences	-	-
Historical Direct Citation	Documents	None	-	-	-

As detailed in Table 1, the keyword co-occurrence network included author keywords appearing at least five times. Association-strength normalization was applied to standardize co-occurrence relationships among terms with different frequencies, and the Louvain algorithm was used to identify clusters of closely related concepts.

The country co-authorship network used fractional counting to account for publications involving authors from multiple countries. A minimum threshold of one recorded collaboration was used to retain international links. For the co-citation network, cited references with at least 20 citations were included, and cosine normalization was applied before Louvain clustering. Thematic mapping used keywords appearing at least five times, while historical direct citation analysis traced citation relationships among documents without applying a minimum threshold.

SDG Alignment Analysis

A systematic content analysis was conducted to assess how the publications contributed to Sustainable Development Goal 4, Quality Education, and Sustainable Development Goal 5, Gender Equality. Each publication in the final corpus was manually reviewed using information from its abstract, keywords, and stated objectives. The coding framework focused on concepts directly related to educational inclusion, equitable access, gender disparities, participation, and empowerment.

Table 2. SDG Alignment Coding Framework

SDG	Keywords/Indicators	Example Paper
SDG 4 (Quality Education)	Inclusive education, equity, access, pedagogy	Ballen et al. (2019)
SDG 5 (Gender Equality)	Women in STEM, gender gap, empowerment	Stoet & Geary (2018)

Table 2 presents the principal indicators used to classify publications according to their relevance to SDGs 4 and 5, together with representative publications from the corpus. As shown in Table 2, publications addressing inclusive educational access, equitable participation, or pedagogical practice were classified as relevant to SDG 4.

Publications examining women's participation, gender gaps, empowerment, or gender equality in STEM were classified as relevant to SDG 5. The framework enabled the study to connect bibliometric patterns with the educational and gender-equity objectives represented in the two SDGs.

Regional Classification and Geographical Analysis

A geographical classification was applied to examine differences in knowledge production and collaboration between the Global North and Global South. Countries were assigned to one of the two regional categories using the classification framework adopted in this study. The country associated with the corresponding author's institution served as the unit of analysis for national and regional productivity indicators. Table 3 provides examples of the regional classification and corresponding-author counts used in the geographical analysis.

Table 3. Examples of Regional Classification and Corresponding-Author Counts

Country	Region	Corresponding-Author Count
United States	Global North	120
India	Global South	45
Germany	Global North	67

Table 3 illustrates how countries were assigned to the Global North or Global South and how publication output was attributed using corresponding-author affiliation. The same classification procedure was applied across the full set of countries represented in the corpus. This regional mapping formed the basis for the finding that 76% of the analyzed output originated from the Global North.

Reliability of the SDG Coding

Inter-rater reliability was assessed for the SDG classification process using a random subset of 50 publications. Agreement among the raters was evaluated using Cohen's kappa, which produced a coefficient of 0.82. This value indicates strong agreement and supports the consistency of the coding framework used to classify publications according to their relevance to SDGs 4 and 5.

Taken together, the structured retrieval process, manual validation, predefined network parameters, SDG coding framework, and regional classification provided a transparent analytical procedure for examining the performance, conceptual structure, intellectual foundations, collaboration patterns, and sustainable-development relevance of research on women in STEM education.

RESULTS AND DISCUSSION

Characteristics of the Bibliometric Corpus

Table 4 summarizes the principal characteristics of the bibliometric corpus, including its publication period, number of documents and sources, citation indicators, references, and authorship profile.

As shown in Table 4, the dataset comprises 348 publications issued between 2006 and 2025 across 211 sources. The large number of publication venues relative to the number of documents indicates that research on women in STEM education is distributed across a broad and multidisciplinary source base. The corpus recorded an annual growth rate of 14.45%, demonstrating a substantial expansion of scholarly attention during the study period. This growth coincided with increasing international attention to inclusive education and gender equality, particularly during the post-2015 Sustainable Development Goal period (Bayram & Öztürk, 2021). However, the bibliometric results establish temporal correspondence rather than a causal relationship between SDG adoption and publication growth.

Table 4. Main Characteristics of the Bibliometric Dataset

Description	Result
Timespan	2006-2025
Sources (Journals, Books, Etc.)	211
Documents	348
Annual Growth Rate (%)	14.45
Document Average Age	4.91
Average Citations per Document	29.41
References	18,973
Authors	1,573
Authors of Single-Authored Documents	35

The citation indicators in Table 4 show that the documents received an average of 29.41 citations despite a relatively low average document age of 4.91 years. This pattern indicates that the corpus combines recent publications with a substantial accumulated citation impact. The 348 documents collectively cited 18,973 references, reflecting engagement with an extensive and interdisciplinary knowledge base (Li et al., 2025).

The authorship indicators further demonstrate that the field is strongly collaborative. Of the 348 publications, 313 were written by more than one author, corresponding to a document-level collaboration rate of 89.9%. At the author level, 1,538 of the 1,573 authors, or 97.8%, participated in co-authored publications. These percentages represent different units of analysis and should not be used interchangeably. The corpus also contained 35 authors of single-authored documents, while the overall author-to-document ratio was approximately 4.5 authors per publication.

Annual Scientific Production and Growth

To show how publication output developed across the study period, Figure 2 presents the annual number of documents published between 2006 and 2025. The figure replaces the former annual-publication table and provides a clearer visualization of changes in research productivity over time.

As illustrated in Figure 2, annual scientific production followed three broad developmental phases. The first phase, covering 2006-2015, was characterized by limited and irregular output. Annual production ranged from one to nine publications, and no consistent year-to-year increase was evident. This pattern indicates that gender-related questions within STEM education remained a comparatively limited research focus during the early period (Oblova et al., 2022).

The second phase, covering 2016-2019, marked a clear expansion of the field. Publication output increased from 16 documents in 2016 to 23 in 2017, declined slightly to 20 in 2018, and then increased to 29 in 2019. The increase after 2015 is consistent with the growing visibility of gender inequality in science, technology, engineering, and mathematics as both an educational and policy concern (López-Iñesta et al., 2020).

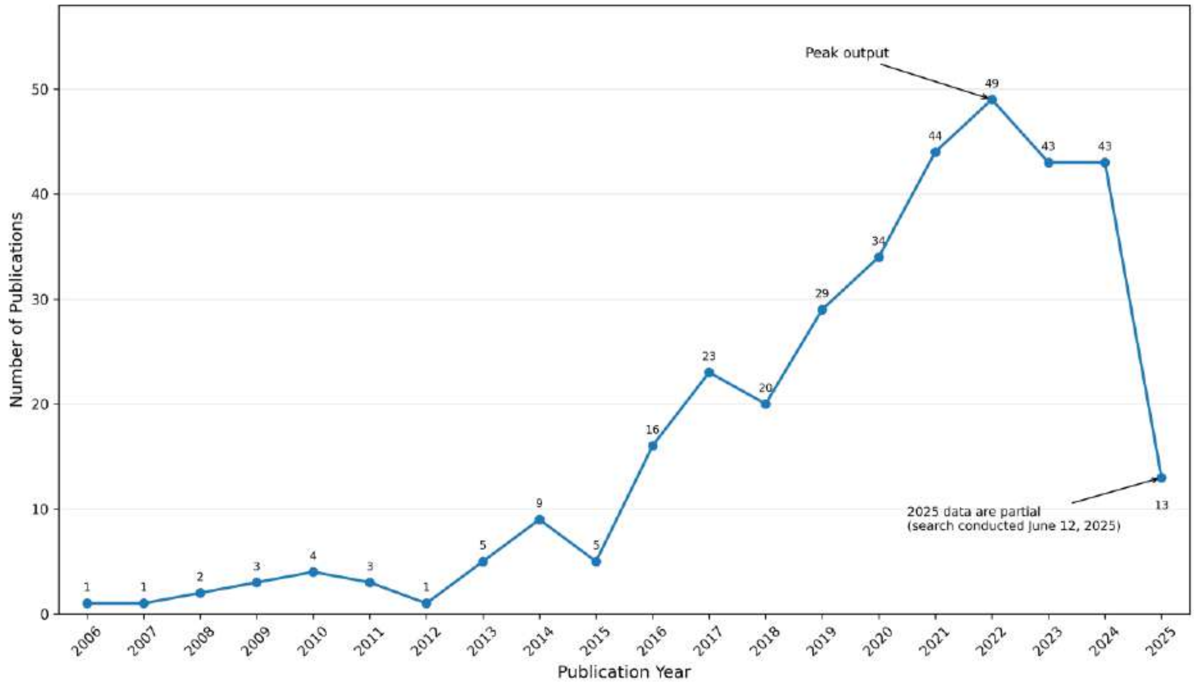

Figure 2. Annual Scientific Production of Women in STEM Education

The third phase began in 2020 and was characterized by sustained high publication output. The annual number of documents increased from 34 in 2020 to 44 in 2021 and reached its highest level of 49 publications in 2022. Output then remained comparatively high, with 43 publications in both 2023 and 2024. Therefore, the trend should be described as sustained high-volume production rather than uninterrupted annual growth.

Publications issued between 2020 and 2025 accounted for 226 of the 348 documents, or 64.9% of the complete corpus. Publications from 2023 onward accounted for 99 documents, or 28.4%, rather than more than 40% of the dataset. The 2025 count of 13 publications should not be interpreted as evidence of decline because the Scopus search was conducted on June 12, 2025 and therefore represents only a partial publication year. Overall, Figure 2 demonstrates that the field expanded markedly after 2015 and maintained a high level of scholarly activity after 2020, consistent with the broader growth of STEM education research during this period (Khalil et al., 2024).

Thematic Linkages Among Keywords, Authors, and Indexed Terms

Figure 3 presents a three-field plot connecting merged keywords, prominent authors, and indexed terms. This visualization shows how the principal topics in the corpus are associated with contributing researchers and database-assigned descriptors.

As shown in Figure 3, three broad thematic patterns characterize the literature. First, gender-related terms such as “female,” “gender,” and “male” are closely connected with educational terms, particularly “students” and “education.” These relationships confirm that the field primarily examines women’s participation, experiences, and outcomes within formal educational settings. The visible connection between gender constructs and students is consistent with research examining participation barriers in STEM classrooms (Dutta & Arnold, 2022).

Second, discipline-specific terms such as “mathematics,” “engineering,” and “science” occupy prominent positions in the plot. Their visibility demonstrates that many studies investigate gender inequality within individual STEM disciplines rather than treating STEM as a completely homogeneous educational domain. Mathematics and engineering are especially prominent, whereas technology-related terms appear less frequently. This imbalance suggests that technology education has received less attention than mathematics, engineering, and science.

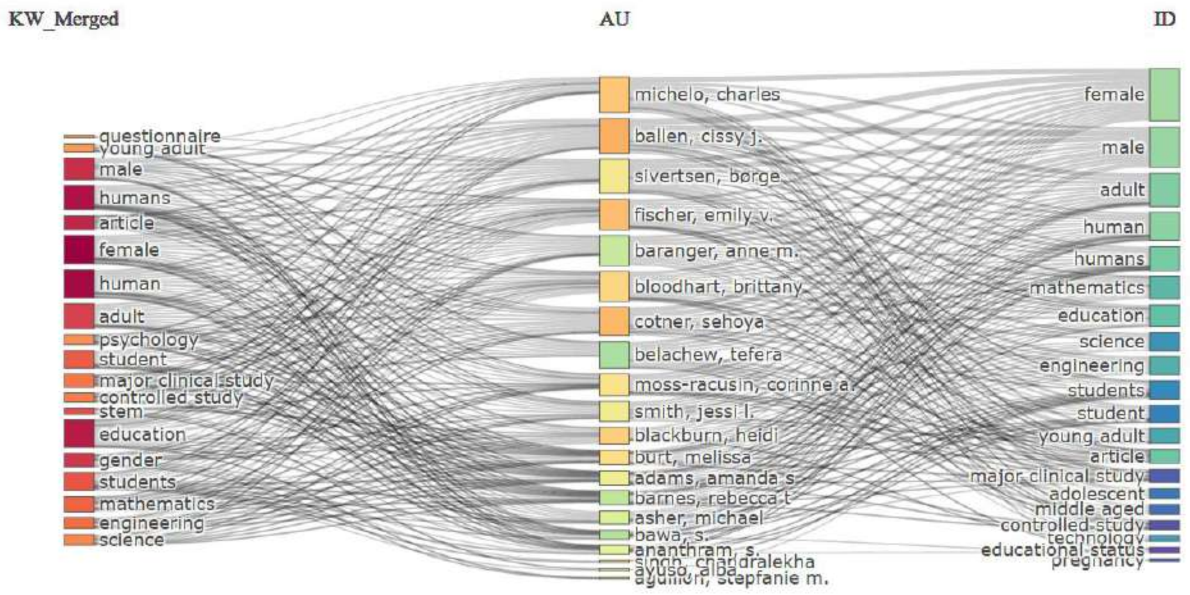

Figure 3. Three-Field Plot

Third, terms such as “questionnaire,” “controlled study,” and “psychology” indicate the presence of empirical and psychological approaches. The visibility of questionnaire-based terminology is consistent with studies that assess attitudes, belonging, identity, and educational experiences through quantitative instruments (Stachl & Baranger, 2020). Nevertheless, some terms in the right-hand field may have been assigned through database-indexing procedures and should not automatically be interpreted as methodologies selected by the authors.

Figure 3 also connects gender-related constructs with psychological and developmental descriptors, including “psychology” and “young adult.” These connections indicate research attention to identity formation, educational experiences, and transitions into STEM study or careers. Terms such as “sustainability” and “clinical study” suggest intersections with environmental, health, and interdisciplinary scholarship. In contrast, intersectional descriptors such as ethnicity, disability, and socioeconomic status are not prominent. Terms related to curriculum, teaching methods, leadership, policy, computer science, and digital literacy also occupy less central positions, identifying areas that remain comparatively underrepresented.

Leading Authors and Patterns of Scholarly Contribution

Table 5 identifies the most productive authors in the corpus and compares their publication counts, fractionalized publication counts, h-indices, and total citations. These indicators provide complementary measures of scholarly productivity and influence.

Table 5. Leading Authors in Women in STEM Education Research

Author	Articles	Articles Fractionalized	H-index	Total Citations
Ballen, Cissy J.	6	1.46	6	304
Cotner, Sehoya	5	1.33	5	240
Fischer, Emily V.	4	0.66	3	197
Michelo, Charles	4	0.85	4	113
Blackburn, Heidi	3	2.0	3	262
Bloodhart, Brittany	3	0.41	3	196
Burt, Melissa	3	0.46	2	100

As reported in Table 5, Ballen was the most productive author, with six publications, an h-index of 6, and 304 total citations. Cotner ranked second in publication volume, with five articles, an h-index of 5, and 240 citations. Fischer and Michelo each contributed four articles, although Fischer recorded a higher citation total. Blackburn, Bloodhart, and Burt each contributed three publications.

The comparison of publication and citation indicators shows that productivity and citation impact did not follow an identical ranking. Blackburn, for example, published three articles but accumulated 262 citations, the third-highest citation count among the listed authors. Ballen combined the highest publication count with the highest h-index and total citation count, whereas Cotner also demonstrated both sustained productivity and substantial citation visibility.

Fractionalized article counts distribute publication credit across the authors of multi-authored documents. Blackburn recorded the highest fractionalized count at 2.00, followed by Ballen at 1.46 and Cotner at 1.33. Lower fractionalized values indicate that an author's publications were shared among larger authorship teams; they do not establish author order, intellectual leadership, or specific contribution roles. The authors listed in Table 5 have contributed to influential work on women's status in STEM, equitable assessment, and student experiences in STEM education (Blackburn, 2017; Cotner & Ballen, 2017; Driessen et al., 2022).

Most Influential Publications

Table 6 presents the five publications with the highest global citation counts. The table includes each document's DOI, total citations, citations per year, and publication source.

Table 6. Most Globally Cited Publications

Paper	DOI	Total Citations	TC per Year	Source
Stoet & Geary (2018)	10.1177/0956797617741719	653	81.63	Psychological Science
Ong et al. (2018)	10.1002/tea.21417	419	52.38	Journal of Research in Science Teaching
Dennehy & Dasgupta (2017)	10.1073/pnas.1613117114	349	38.78	Proceedings of the National Academy of Sciences
Makarova et al. (2019)	10.3389/feduc.2019.00060	310	44.29	Frontiers in Education
Sheltzer & Smith (2014)	10.1073/pnas.1403334111	305	25.42	Proceedings of the National Academy of Sciences

Table 6 shows that Stoet and Geary (2018) was the most highly cited document, receiving 653 citations and an average of 81.63 citations per year. The study introduced the gender-equality paradox as a framework for examining cross-national differences in women's participation in STEM education. Its citation performance indicates substantial influence within comparative and policy-oriented research.

Ong et al. (2018) ranked second, with 419 citations and 52.38 citations per year. By examining counterspaces for women of color in STEM higher education, the study provided an intersectional perspective on persistence, identity, and educational success. Dennehy and Dasgupta (2017) received 349 citations and examined female peer mentoring as an intervention supporting women's academic experiences and retention in engineering.

Makarova et al. (2019) accumulated 310 citations and 44.29 citations per year. Their study examined the relationship between gender stereotypes in mathematics and science and students' STEM career aspirations. Sheltzer and Smith (2014), with 305 citations, addressed gender disparities in the employment of women within elite life-science laboratories.

Collectively, the publications listed in Table 6 show that the most influential literature addresses cross-national variation, intersectionality, mentoring, gender stereotypes, academic careers, and institutional inequality. Their distribution across broad scientific and specialized educational journals also indicates multiple pathways through which women-in-STEM research has reached both interdisciplinary and field-specific audiences.

Leading Publication Sources

Table 7 compares the leading publication sources according to number of publications, h-index, g-index, m-index, total citations, and the first year in which each source appeared in the corpus.

Table 7. Leading Sources and Local Impact Indicators

Source Name	NP	H-index	G-index	M-index	TC	PY Start
PLOS ONE	36	18	36	1.8	1548	2016
CBE-Life Sciences Education	19	10	19	0.5	525	2006
Sustainability (Switzerland)	13	8	13	1.143	173	2019
International Journal of Environmental Research and Public Health	7	5	7	0.385	185	2013
Proceedings of the National Academy of Sciences of the United States of America	6	6	6	0.5	1326	2014

As shown in Table 7, PLOS ONE was the most productive source, publishing 36 documents. It also recorded the highest source-level h-index of 18 and the highest total citation count of 1,548. Its m-index of 1.800 indicates comparatively rapid accumulation of citation impact relative to the period since its first publication in the corpus in 2016.

CBE-Life Sciences Education ranked second in publication volume, with 19 documents, an h-index of 10, and 525 citations. Its first relevant publication appeared in 2006, showing its sustained contribution to pedagogical research on equity and participation in STEM education. Sustainability published 13 documents beginning in

2019, reflecting the increasing visibility of women-in-STEM scholarship in sustainability-oriented outlets.

The International Journal of Environmental Research and Public Health contributed seven publications and received 185 citations, indicating an intersection between women-in-STEM scholarship and public-health or interdisciplinary research. The Proceedings of the National Academy of Sciences of the United States of America published only six documents but accumulated 1,326 citations. This high citation total was partly associated with influential publications such as Dennehy and Dasgupta (2017) and Sheltzer and Smith (2014).

Table 7 therefore demonstrates that source productivity and citation influence followed different patterns. PLOS ONE provided the largest publication volume and the highest cumulative source impact, CBE-Life Sciences Education maintained a sustained specialized presence, and PNAS disseminated a small number of exceptionally highly cited studies.

Conceptual Structure of the Field

To identify the principal conceptual relationships within the literature, Figure 4 maps the co-occurrence of keywords across the corpus. Node size represents term frequency, links indicate co-occurrence relationships, and colors distinguish clusters of closely connected terms.

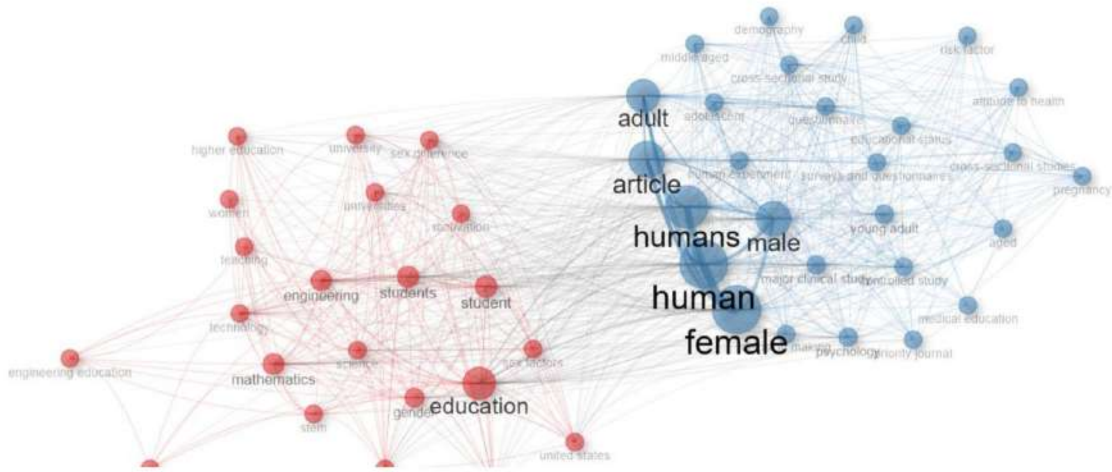

Figure 4. Co-Occurrence Network

Pedagogical and Educational Cluster

Figure 4 reveals two broad conceptual clusters. The red cluster has a predominantly pedagogical and educational orientation. Its most visible terms include "education," "student," "gender," "mathematics," and "engineering." These terms indicate that a substantial portion of the literature examines gendered participation, achievement, and experience within formal educational environments.

The prominent positions of mathematics and engineering demonstrate discipline-specific attention to fields in which gender stereotypes and participation inequalities remain major concerns (Maloshonok, 2023). Connections with terms related to teaching, higher education, career development, and academic achievement further suggest that the cluster addresses relationships between institutional practices, learning environments, and gendered educational outcomes (Miller, 2018). Its structure is consistent with social-constructivist perspectives that emphasize the influence of educational and socio-emotional environments on student experience (Camacho & Alexander, 2025).

Demographic and Indexing Cluster

The blue cluster is dominated by demographic and database-indexing terms, including "female," "male," "adult," "human," "humans," and "article." These terms show that many records distinguish participants according to sex and age. However, descriptors such as "human," "humans," and "article" may partly reflect indexing conventions rather than substantive theoretical or methodological orientations.

The blue cluster should therefore not automatically be characterized as a quantitative, biomedical, or clinical research paradigm. Its relative separation from explicitly educational terms may indicate that some publications focus more strongly on individual-level, psychological, demographic, or health-related characteristics than on institutional educational processes. Individual-level and biotechnology-informed approaches are present in the wider literature (Du & Zhao, 2024), although reductionist interpretations of complex social identities require caution (Pirruccello, 2012).

Overall, Figure 4 shows that women in STEM education research combines pedagogical and institutional perspectives with demographic and individual-level analyses. The limited connections between these clusters also suggest an opportunity for studies that integrate individual experiences with classroom, institutional, and policy contexts.

Intellectual Structure

Figure 5 presents the co-citation network used to identify the principal intellectual foundations of women in STEM education research. References positioned within the same cluster are frequently cited together and therefore represent related knowledge traditions.

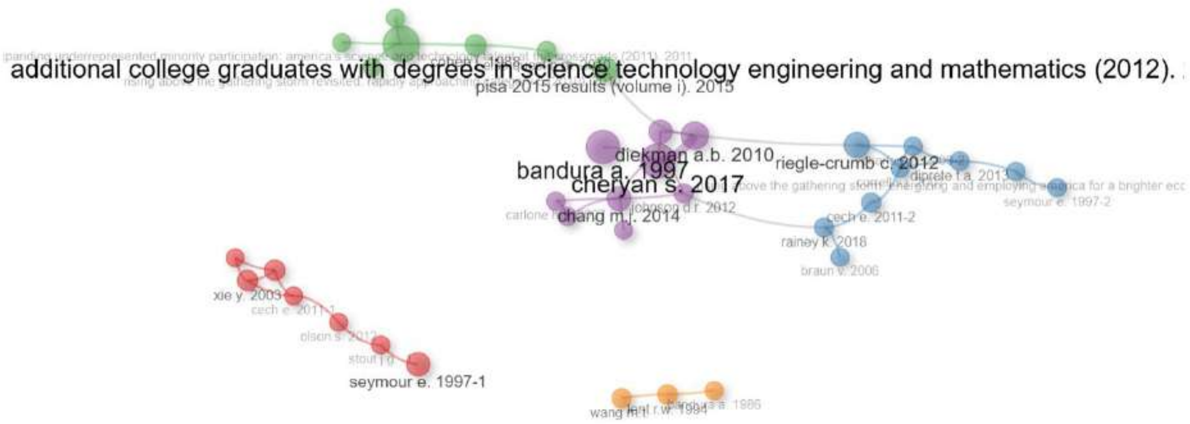

Figure 5. Co-Citation Network

As displayed in Figure 5, the co-citation network consists of five intellectual clusters. Cluster 2, which includes work associated with Riegle-Crumb, Correll, and major policy reports, occupies an important bridging position. Its comparatively high betweenness centrality indicates that it connects educational sociology, workforce participation, and policy-oriented research. Government and policy documents such as Rising Above the Gathering Storm contribute to this connection by linking academic research with broader educational and workforce priorities.

Cluster 4, associated with Cheryan, Diekman, and Corbett, represents a prominent social-psychological knowledge base. Cheryan and Diekman recorded PageRank scores of 0.061 and 0.035, respectively, indicating central positions within the co-citation structure. Correll also occupied an influential position, with a PageRank score of 0.044. These authors connect research on stereotypes, belonging, identity, and participation in STEM settings.

Figure 5 further shows that influential contemporary scholarship builds on recurring foundational works. These include Stoet and Geary's (2018) cross-national analysis of the gender-equality paradox, Dennehy and Dasgupta's (2017) peer-mentoring intervention, and social-psychological research associated with Cheryan and colleagues. Their recurrent co-citation indicates that studies of identity and intervention are embedded within broader theoretical, sociological, and policy-oriented foundations.

Cluster 5 includes Bandura (1989), demonstrating the continuing influence of social cognitive theory. Bandura's work should be identified as a foundation of social cognitive approaches rather than as Social Cognitive Career Theory itself. Cluster 1, associated with Seymour, Ceci, and Xie, represents earlier scholarship on women's participation, inequality, and attrition in science. Cluster 3 contains policy documents such as Engage to Excel and PISA reports, which connect academic research with educational implementation and policy debates.

Taken together, the five clusters in Figure 5 indicate that the field draws on sociological, psychological, educational, and policy-oriented knowledge bases. The prominence of Clusters 2 and 4 suggests increasing attention to structural barriers, belonging, identity, and evidence-based intervention. This orientation is reflected in research on recruitment inequalities (Sheltzer & Smith, 2014), mentoring and educational experience (Dennehy & Dasgupta, 2017), and policy initiatives intended to sustain women's representation in STEM (Moss-Racusin et al., 2021).

Historical Development of Influential Literature

Figure 6 presents the historiograph of the corpus, tracing direct citation relationships among 14 influential publications. The visualization indicates how earlier studies informed subsequent work and how major research themes developed over time.

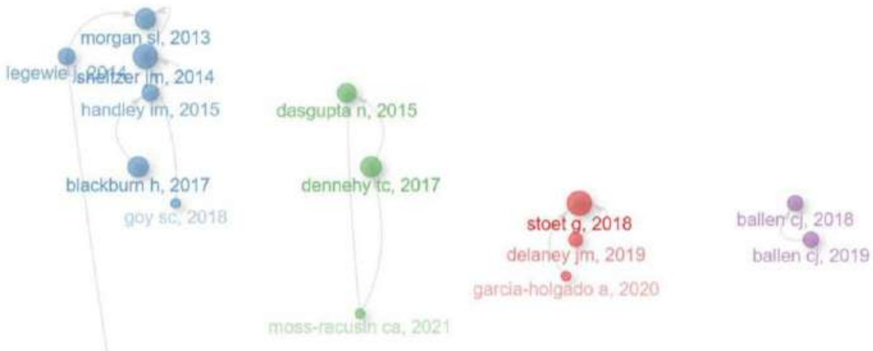

Figure 6. Historiograph

Figure 6 identifies several recurring historical themes, including gender bias in academic recruitment (Sheltzer & Smith, 2014), women's representation in higher education and leadership (Blackburn, 2017), and the influence of peer and mentoring relationships on participation and retention (Dasgupta et al., 2015; Dennehy &

Dasgupta, 2017). These linked studies demonstrate that the field has examined gender disparities across educational, institutional, and professional stages.

The historiograph also combines different methodological and analytical traditions. Longitudinal studies examine persistent gender segregation in higher education and its relationship with labor-market outcomes (Zheng & Weeden, 2023), whereas experimental studies assess interventions such as peer mentoring (Dennehy & Dasgupta, 2017). The historical network therefore incorporates educational-policy research, social-psychological analysis, cross-cultural comparison, and classroom-level intervention.

A central pattern visible in Figure 6 is the movement from documenting gender disparities toward testing and recommending institutional responses. Moss-Racusin et al. (2021) emphasized evidence-based policy initiatives designed to support the sustainable representation of women in STEM. Ballen et al. (2018, 2019) examined how class size and classroom participation structures may affect equity in STEM education. These works connect institutional conditions with individual educational experiences.

The historiograph further includes research addressing cultural and intersectional contexts. Garcia-Holgado et al. (2020) compared support in engineering education in Brazil and Spain, while Stoet and Geary (2018) examined cross-national variation in gender equality and STEM participation. Other influential studies documented continuing challenges, including responses to evidence of subtle gender bias (Handley et al., 2015) and the contribution of educational segregation to labor-market segregation (Zheng & Weeden, 2023).

Local Citation Scores among the documents in Figure 6 ranged from 1 to 14, whereas Global Citation Scores reached 653. These differences show that some publications were especially influential within the analyzed corpus, while others achieved broader recognition across the international scientific literature. Overall, the historiograph demonstrates increasing attention to interventions and institutional reform while retaining a strong foundation in research documenting persistent inequality.

International Collaboration Structure

Figure 7 maps the international collaboration network based on co-authorship relationships among countries. The thickness and frequency of connections indicate the relative intensity of collaboration between national research systems.

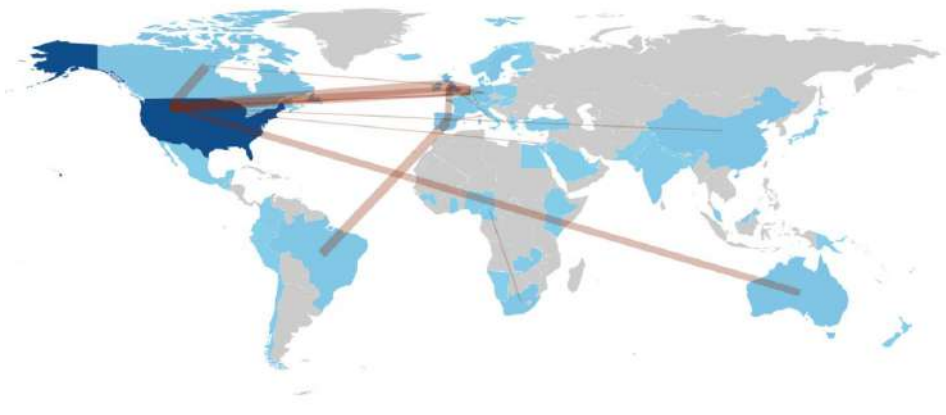

Figure 7. Countries Collaboration Map

As shown in Figure 7, the United States, the United Kingdom, Germany, and the Netherlands occupy central positions in the international collaboration network. The

United States recorded five collaborations with the United Kingdom, four with Canada, four with the Netherlands, and two with Germany. These relationships establish the United States as the most visible collaboration hub in the network.

The United Kingdom maintained four collaborations with the Netherlands, two with Germany, and one each with France, India, and South Africa. Germany collaborated twice each with the Netherlands and Belgium and once each with South Africa and China. The Netherlands also maintained connections with France, Belgium, Pakistan, and South Africa. These patterns demonstrate that the most frequent international collaborations were concentrated among North American and European institutions, although several cross-regional partnerships were also present.

Participation by Global South countries was visible but generally involved lower-frequency relationships. The four collaborations between Brazil and Spain represent a cross-regional or North-South partnership rather than a South-South collaboration. South-South relationships included India-Kenya, India-Ethiopia, South Africa-Nigeria, and South Africa-Ghana, each with one recorded collaboration. These links demonstrate participation by institutions from Africa, Asia, and Latin America but remain less frequent than collaborations among the principal Global North hubs.

The concentration of high-frequency collaborations among high-income countries may contribute to inequalities in research resources, agenda-setting capacity, and international visibility (Csomós et al., 2020). Partnerships such as United States-Bangladesh and United Kingdom-Nepal indicate some diversification of the network, although each was represented by only one collaboration.

Overall, Figure 7 depicts an internationally connected but geographically uneven research landscape. The network includes emerging cross-regional and South-South relationships, but its most intensive connections remain concentrated in the Global North. More sustained and reciprocal partnerships with underrepresented national research systems could broaden the geographical contexts and educational perspectives represented in women in STEM education research (Hou et al., 2021).

SDG Alignment and Regional Distribution

Using the coding framework summarized in Table 2, the publications were assessed for their relevance to SDG 4 and SDG 5. The recurring focus on equitable access, inclusive pedagogy, participation, retention, gender gaps, and empowerment indicates that the corpus is substantively aligned with both goals. This alignment is especially visible in studies of classroom participation, mentoring, institutional barriers, and women's persistence in STEM education.

The regional classification illustrated in Table 3 showed that 76% of the analyzed output originated from the Global North. This geographical concentration is consistent with the collaboration structure shown in Figure 7 and indicates that the field's international expansion has not yet produced balanced regional representation. Consequently, the evidence base remains more reflective of Global North institutions and educational systems than of the diverse contexts represented across the Global South.

Discussion

Conceptual and Intellectual Development of the Field

The conceptual, intellectual, and social structures identified in this study indicate that research on women in STEM education has gradually moved beyond documenting gender disparities toward examining their underlying mechanisms and evaluating evidence-based responses. The keyword co-occurrence network revealed two broad but connected conceptual clusters. The first cluster has a pedagogical and institutional orientation, centered on terms such as "education," "gender," "students," "mathematics," and "engineering." This cluster reflects sustained attention to classroom participation, curriculum, academic achievement, career development, and discipline-specific barriers. Its structure supports the view that women's participation in STEM is shaped not only by individual characteristics but also by learning environments, institutional practices, and gendered expectations within particular disciplines (Dutta & Arnold, 2022; Maloshonok, 2023; Miller, 2018).

The second cluster is dominated by demographic and database-indexing terms, including "female," "male," "human," "humans," and "adult." These descriptors indicate substantial attention to sex- and age-based differences, but they should not automatically be interpreted as evidence of a distinct quantitative or clinical research paradigm. Some terms may reflect indexing conventions rather than the authors' theoretical or methodological choices. Nevertheless, the relative prominence of individual-level descriptors suggests that part of the literature continues to examine psychological, demographic, and behavioral characteristics separately from broader educational and institutional conditions. Greater integration between these levels of analysis would provide a more complete explanation of how individual experiences interact with classroom practices, organizational structures, and social inequalities (Pirruccello, 2012).

The intellectual structure further demonstrates that the field draws on sociological, psychological, educational, and policy-oriented knowledge bases. Seminal studies such as Stoet and Geary's cross-national analysis and Dennehy and Dasgupta's peer-mentoring intervention remain central because they address different dimensions of women's participation in STEM: comparative national patterns, identity, belonging, mentoring, and retention (Dennehy & Dasgupta, 2017; Stoet & Geary, 2018). These studies are complemented by research on institutional hiring inequalities, classroom participation, stereotypes, and policy interventions (Ballen et al., 2018, 2019; Makarova et al., 2019; Moss-Racusin et al., 2021; Sheltzer & Smith, 2014). The historiographic pattern therefore suggests a substantive shift from identifying disparities toward designing and evaluating interventions at the classroom, institutional, and policy levels.

This development does not imply that the field has fully resolved the causes of gender inequality in STEM. Rather, it shows that contemporary scholarship increasingly treats gender disparities as outcomes of interconnected psychological, educational, cultural, and structural processes. The growing influence of intersectional research, particularly work examining the experiences of women of color, further challenges approaches that treat women as a homogeneous category (Ong et al., 2018). However, the limited visibility of ethnicity, disability, and socioeconomic status in the keyword network indicates that intersectionality has not yet become fully embedded across the field.

Collaboration and Geographical Inequality

The social structure of the field is characterized by extensive collaboration but uneven geographical representation. At the document level, 313 of the 348 publications were multi-authored, corresponding to a collaboration rate of 89.9%. At the author level, 1,538 of the 1,573 authors, or 97.8%, participated in co-authored publications. These findings demonstrate that women in STEM education research is predominantly collaborative, although the two percentages represent different units of analysis and should not be used interchangeably.

Despite this high level of collaboration, the international network remains concentrated around the United States, the United Kingdom, Germany, and the Netherlands. The manuscript's regional analysis further indicates that 76% of the scholarly output originated from the Global North. This concentration suggests that collaboration intensity does not necessarily produce geographical or epistemic diversity. Research partnerships may be internationally connected while still privileging the institutions, theoretical traditions, funding priorities, and educational contexts of high-income countries. Similar inequalities have been observed in broader patterns of international scientific collaboration, where research capacity and visibility remain concentrated in established academic centers (Csomós et al., 2020; Hou et al., 2021).

The network includes cross-regional and South-South connections involving India, South Africa, Kenya, Ethiopia, Nigeria, Ghana, Pakistan, Bangladesh, and other countries. However, these relationships occur less frequently than collaborations among the principal Global North hubs. This imbalance matters because interventions developed in well-resourced educational systems may not be directly transferable to contexts characterized by different cultural expectations, institutional capacities, labor markets, or forms of gender inequality. The geographical concentration of knowledge production may therefore limit the external relevance of theoretical models and intervention strategies.

More equitable collaboration requires more than including Global South institutions as data-collection sites or junior partners. Future research consortia should support shared agenda setting, methodological decision-making, authorship, funding allocation, and interpretation of findings. Such arrangements would broaden the field's empirical base and reduce the risk of applying solutions developed for a narrow set of educational and cultural settings to substantially different contexts.

Contributions to Sustainable Development Goals 4 and 5

Research on women in STEM education is substantively aligned with SDG 4 on Quality Education and SDG 5 on Gender Equality. The literature contributes to Target 4.3 by examining women's access to technical, vocational, and higher education; to Target 4.5 by identifying gender disparities in participation, achievement, and retention; and to Target 5.5 by addressing women's representation, leadership, and participation in academic and professional decision-making. Studies of classroom participation, mentoring, institutional bias, and inclusive educational practices provide an empirical basis for understanding the conditions that support or restrict women's progression through STEM pathways (Ballen et al., 2018, 2019; Dennehy & Dasgupta, 2017; Moss-Racusin et al., 2021).

The marked increase in publications after 2015 coincides temporally with the adoption of the Sustainable Development Goals. This pattern indicates that women's participation in STEM became increasingly visible within global educational and policy discussions during the SDG era. However, the bibliometric design does not establish that the SDGs directly caused the growth in publication output. The increase may also reflect broader developments, including institutional diversity initiatives, greater recognition of gender bias, the maturation of STEM education research communities, and expanding interest in evidence-based educational reform (López-Iñesta et al., 2020; Ro et al., 2021).

The field contributes to the SDGs by moving beyond descriptive advocacy and generating evidence about potentially effective interventions. Peer mentoring can strengthen women's academic experiences and retention in engineering, while classroom structures such as smaller classes may support more equitable participation (Ballen et al., 2018, 2019; Dennehy & Dasgupta, 2017). Research on institutional hiring and evaluation practices also demonstrates that gender inequality cannot be addressed only by changing women's aspirations or behavior; universities and scientific organizations must also reform the structures through which opportunities are distributed (Handley et al., 2015; Sheltzer & Smith, 2014).

Nevertheless, the contribution of this research to SDGs 4 and 5 remains incomplete. The dominance of Global North studies, limited attention to technology-specific education, and insufficient intersectional analysis restrict the applicability of existing evidence. A policy or intervention may be effective in one educational system but less appropriate in another. Similarly, interventions that address gender without considering ethnicity, disability, socioeconomic status, or cultural context may benefit only a subset of women and leave other forms of exclusion unchanged (Ong et al., 2018; Rodríguez et al., 2023; Tricco et al., 2023).

Research Gaps and Future Directions

The findings identify several priorities for future research. First, technology education requires more systematic attention. Compared with science, mathematics, and engineering, terms associated with computer science, digital literacy, artificial intelligence, and technology education were less prominent. This gap is increasingly important because digital technologies are reshaping educational participation, professional pathways, and the skills required in contemporary STEM fields.

Second, researchers should embed intersectional analysis throughout the research process rather than treat it as a specialized subtopic. Future studies should examine how gender interacts with race, ethnicity, socioeconomic position, disability, geography, and other dimensions of inequality. Such analyses are particularly important in early STEM education, where identity, stereotypes, and educational expectations begin to influence later choices and participation (Edosomwan et al., 2025; Xu et al., 2025).

Third, the field needs more context-sensitive studies from the Global South, including research on vocational education, rural education, resource-constrained institutions, and transitions from education to employment. Locally grounded research can determine whether widely cited interventions, such as mentoring or inclusive classroom practices, operate similarly across different cultural and institutional environments. Comparative studies should therefore examine not only whether an intervention works but also for whom, under what conditions, and through which mechanisms.

Fourth, mixed-methods and longitudinal designs should connect bibliometric patterns with the lived experiences of women in STEM. Quantitative studies can identify broad participation trends and relationships among variables, while qualitative evidence can explain how institutional cultures, stereotypes, mentoring relationships, and educational practices are experienced in specific contexts.

Longitudinal research is also needed to follow women's pathways from early education through higher education, employment, and leadership.

Overall, the field has developed a substantial intellectual and collaborative foundation for advancing gender equity in STEM education. Its next stage should combine pedagogical innovation with structural reform, deepen intersectional and geographically diverse analysis, and strengthen reciprocal North-South research partnerships. These priorities would improve both the scientific relevance of the field and its capacity to contribute meaningfully to the achievement of SDGs 4 and 5.

Study Limitations

This study has several limitations. First, the analysis was restricted to Scopus-indexed, English-language, open-access publications and may therefore underrepresent non-English, closed-access, and locally indexed scholarship. Second, citation counts are time-sensitive and generally favor older publications that have had more time to accumulate citations.

Third, the search strategy and metadata-based keyword filters may have excluded relevant studies that used different terminology or included records only indirectly related to women in STEM education. Fourth, the 2025 publication count is incomplete because data were retrieved on June 12, 2025. Fifth, regional findings depend on the selected Global North-Global South classification and on the use of corresponding-author affiliation as the unit of analysis.

Finally, author keywords and indexed terms may reflect database conventions as well as substantive research themes. These limitations should be considered when interpreting the productivity, impact, thematic, and geographical patterns reported in this study.

CONCLUSIONS

This bibliometric analysis maps the development of research on women in STEM education from 2006 to 2025. Based on 348 Scopus-indexed publications, the findings show that the field has expanded substantially and developed a strong collaborative and interdisciplinary knowledge base. The literature has increasingly moved from documenting gender disparities toward examining institutional barriers, educational experiences, mentoring, inclusive pedagogy, and evidence-based interventions. These themes are substantively aligned with Sustainable Development Goal 4 on Quality Education and Sustainable Development Goal 5 on Gender Equality.

Despite this progress, the research landscape remains geographically uneven. Most publications and high-frequency collaborations originate from the Global North, limiting the representation of educational systems, cultural conditions, and women's experiences in underrepresented regions. The analysis also identifies limited attention to technology-specific education and insufficient integration of intersectional perspectives involving race, ethnicity, socioeconomic status, disability, and geographical context. These gaps restrict the applicability of existing theories and intervention models across diverse populations and institutional settings.

Future research should therefore examine technology education more systematically, expand intersectional and context-sensitive studies in the Global South, and evaluate whether established interventions can be adapted to vocational, technical, and resource-constrained educational environments. Equitable North-South research partnerships are also needed to support shared agenda setting, methodological decision-making, authorship, and interpretation. By combining demographic analysis with pedagogical, institutional, and mixed-methods approaches, the field can develop more comprehensive explanations of the barriers women face and generate more inclusive evidence for advancing gender equity across global STEM education systems.

RECOMMENDATIONS

The findings support several priorities for future research, policy, and international collaboration. First, researchers should give greater attention to technology education, including computer science, digital literacy, artificial intelligence, and related fields. These areas remain less visible than science, engineering, and mathematics in the analyzed literature, despite their growing importance in education and employment. Future studies should examine participation, identity development, retention, and learning experiences within technology-focused programs across different educational levels.

Second, future research should integrate intersectional frameworks throughout study design, data collection, analysis, and interpretation. Researchers should examine how gender interacts with race, ethnicity, socioeconomic position, disability, geography, and other dimensions of inequality. This approach is especially important in the Global South, where women's STEM experiences may be shaped by educational access, infrastructure, cultural expectations, labor-market conditions, and institutional resources that differ from those commonly represented in Global North research.

Third, universities, funding agencies, and research organizations should develop equitable international consortia that support sustained collaboration between institutions in the Global North and Global South. These partnerships should extend beyond data collection and include shared responsibility for setting research priorities, designing methods, managing resources, interpreting findings, and assigning authorship. Such arrangements would help reduce geographical and epistemic imbalances while improving the contextual relevance of the resulting evidence.

Fourth, researchers should evaluate how evidence-based interventions-such as mentoring, inclusive pedagogy, equitable classroom participation, and institutional reform-can be adapted to local conditions. Greater attention should be given to vocational and technical education, rural and resource-constrained institutions, and transitions from education to employment. Comparative, longitudinal, and mixed-methods designs would help determine which interventions work, for whom they work, and under what institutional and cultural conditions.

Implementing these recommendations may be constrained by limited funding for interdisciplinary and cross-national research, unequal institutional capacity, restricted access to localized data, systemic biases in scholarly publishing, and differences in methodological traditions across regions. Addressing these barriers will require targeted funding, capacity-building initiatives, transparent data-sharing arrangements, and institutional support for reciprocal collaboration. These measures would enable future research to expand not only in volume but also in geographical representation, methodological rigor, inclusivity, and practical relevance to the achievement of SDGs 4 and 5.

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The authors declare that they have no financial, professional, or personal conflicts of interest that could have influenced the conduct, interpretation, or reporting of this study.

Data Availability
Data availability is not applicable to this article because no new data were created or analyzed in this study.

Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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M Abdul Ghofur	✓						✓			✓		✓		✓
Eka Indah Nurlaili			✓	✓		✓				✓			✓	
M Arief Rafsanjani			✓	✓	✓			✓		✓				
R Yonisa Kurniawan			✓	✓		✓				✓	✓			
Prattana Srisuk		✓						✓		✓				

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

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