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Review Article

Exploring gender in ICT integrated STEM education: A bibliometric study

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ABSTRACT

Gender inequalities are one of the principal issues that academic gurus and policy makers have noted in information and communication technology (ICT) integrated STEM education. Therefore, this bibliometric analysis has the research objectives to investigate the quantity of research carried out and published over the years on gender in STEM education. Data source was Scopus database with time frame from 2010-2024. According to our investigation of the literature, scholarly work that focuses on gender in ICT integrated STEM education has been on the rise in the last ten years proving that gender issues are worth considering in this context. This study examines the evolution of research output and trends in the incorporation of gender studies into ICT integrated STEM education. The findings indicate a notable increase in research activity over the years, with a peak in article production and citations in 2022 and 2023. Noteworthy patterns of collaboration among prolific authors underscore the interdisciplinary nature of the field. Keyword analysis highlights a strong focus on gender-related issues, such as gender differences and disparities, reflecting a concerted effort to address gender inequalities in ICT integrated STEM education. The global distribution of research contributions emphasizes the universal relevance of gender issues in ICT integrated STEM, with the USA leading in article production. Key journals and institutions are identified as pivotal in advancing gender equity in ICT integrated STEM, with funding agencies playing a crucial role in driving research agendas. The interdisciplinary nature of research on gender in ICT integrated STEM is evident, with various disciplines contributing to a comprehensive understanding of gender dynamics in educational and professional contexts.

Keywords: gender, ICT, STEM education, bibliometric review

INTRODUCTION

Education about information and communication technology (ICT) has become an important part of contemporary STEM education programs, and women-men differences in ICT engagements continue to be a problematic area in most education systems around the globe (Cheryan et al., 2017). Due to the incorporation of ICT expertise into the STEM curriculum, there are fascinating prospects to fix gender gaps as digital literacy grows a crucial element in enhancing a professional career in science, technology, engineering, and mathematics disciplines (Wang & Degol, 2017). Knowledge of gender and its interaction on access, engagement and outcomes in ICT education is of essence in formulation of inclusive pedagogical strategies that can bridge digital gender gaps as well as ensuring equitable involvement in technology-rich learning environment (Vekiri & Chronaki, 2008).

The contemporary view of the word gender as it applies to STEM learning considers the constant gender issues and or barriers that women encounter in STEM careers. Studies have it that women comprise only 17% of the STEM population and very few women go for STEM careers (Ortiz-Martínez et al., 2023). Current research focuses on increasing girls' opportunities and enforcing them to participate in robotics competitions as well as STEM subjects, which raises the awareness of the necessity of more encouragement from coaches, mentors, and parents (Chiang et al., 2023). Moreover, gender-related disparities in and between online and traditional STEM education contexts have been revealed that female students are more successful in traditional classes, while indicating slightly higher performance among male learners in the context of online classes (Idrizi et al., 2023). Performing gender in STEM research laboratories and practice results in the male and female researchers in the laboratories doubting themselves more and feeling less like they belong to the laboratories since the gender norms and relations in the laboratories are clearly manifested (Maji et al., 2023). Gender mainstreaming in higher education also endeavors to provide equal opportunities and equal gender in the STEM field and equality in the methodologies and classroom conduct (Peña et al., 2021).

The subject area, funding sources, and culture create a foundation for the alteration of gender definition that is related to STEM education. A literature review concerning the underrepresentation of Females in STEM careers reveals that gender inequality still exists (Manly et al., 2018). Literature review has also focused on the antecedents of women's choices of STEM fields of study, including an analysis of personal and environmental influences on their education, with the support of parents, teachers, and significant others being stressed (Pasha-Zaidi & Afari, 2016). Furthermore, activities encouraging STEM participation from marginalized and minority groups have been deemed crucial, while the need for systems' change to replace archaic mental structures, which create STEM participation imparity, has been noted (Leibnitz et al., 2022). Several strategies have been proposed concerning the approach of the gender dimension in teaching practices in STEM higher education, including the principles of equal opportunities and gender equality (Hagan et al., 2016). In conclusion, the changes in meaning of gender in STEM education imply that there is a need to improve the support for and representation of all people in STEM occupations.

The way gender is conceived in STEM education plays a major role in determining the learners' success rates and consequently their involvement in STEM programs. STEM has been found to promote a supremacy of masculinity that negatively impacts those who do not fit the mold, in this case women experience a feminization penalty in STEM majors (Simon et al., 2016). Chilly or hostile experience in institutional contexts, especially in the male-dominated fields of STEM hinders women's participation, retention and completion rates in STEM (Rincón & George-Jackson, 2016). Further, students' gender stereotypes can affect their perception of the role of male and female instructors in STEM and their perception of teaching effectiveness (Bowman et al., 2022). Moreover, differences in the delimitation of STEM disciplines can introduce certain controversy and subsequently distort the results. Thus, stressing the need for the standardization of classification criteria to facilitate fair comparisons and problem-solving to promote gender equality for women in STEM (Ashlock et al., 2021).

Gender has always been an important aspect if equal representation in STEM education and therefore dispelling the gender myths is quite important in the enhancement of gender parity in STEM courses. According to the available literature, it is evidenced that gender inequality prevails in STEM education where studies show that women are lacking behind in STEM employment (Miralles-Cardona et al., 2023). Students are influenced by the teachers in matters regarding gender perceptions in STEM, hence the need to address

children's classroom gender stereotyping in early learning centers according to Wang (2023). Additionally, for instance, a Robotics competition keeps on revealing that a girl child is rare, hence the need to encourage her to attain, compete and succeed in STEM related activities (Koul et al., 2021). Gender features such as barriers, stereotype and support systems are critical for promotion of Diversity in STEM education (Achtzehn et al.,2023).

LITERATURE REVIEW

Sort findings from a systemic review on gender in STEM education can be listed; gendered factors for women's persistence in STEM studies; significance of general system design (GSD) for STEM pedagogy; STEM enrollment gap; gendered processes affecting women researchers in reputable institutions. Sociocultural, psychological, supportive, environmental, and pedagogical factors influencing women and girls' retention in STEM are (Joseph, 2023). Inclusion of GSD-inclusive STEM teaching can develop nonbiased and equitable STEM learning environment to improve the save school climate for the LGBTQ students (Wright & Delgado, 2023). Women even now experience difficulties engaged in STEM programs and they don't find friendly environments as their male counterparts, competitive environments and less empathetic teachers discourage them (Maloshonok et al., 2022). In the STEM course, gender comparison of learner achievement in traditional and online system reveals that female student's achievements are higher than male students in traditional learning environment. While male student's performance is slightly better in the online mode of learning and that the traits like consciousness have a positive significant correlation with learners' achievements (Ferati et al., 2023). Gendered processes in STEM research laboratories cause insecurity in women researchers; the impact which has individual and contextual aspects (Steffen et al., 2023).

In the past, the representation of women in STEM professions has remained low even with increased women's education and achievements (Guevara-Ramírez et al., 2022). Despite women's increasing participation in STEM education, the labor market presents a low percentage of women occupying STEM careers, at 28% (Daniela et al., 2022). Researchers have established that components that may include interest, confidence, parental support, and role models affect women's' choice in opting for higher studies in STEM. Also, the analysis of the gendered processes in STEM-based employment has been duly researched where it concluded that the processes cause low confidence in women researchers (Verdugo-Castro et al., 2022). Some measures that have been ensued to mitigate such trends include architectural changes such as mentoring, online tools, and awareness creation efforts like workshops targeting to ensure and encourage women's participation in stem fields (Cheryan et al., 2017). It is important to identify and disrupt existing paradigms and practices benefiting the dominant groups at the expense of the underrepresented groups when it comes to STEM education and employment of talent.

These problems are gender issues in the sciences that are still significant; women's minority representation and challenges faced by the group, such as male-dominated environments, harassment, and ethnic diversity (Moè et al., 2020; Sarabi & Smith, 2023). The findings of these studies indicate that women's lesser attraction towards male stereotyped STEM careers is due to such stereotypes in the context of self-identity, congruity and social identification in STEM domains (Schmader, 2023). In addition, STEM academic cultures devalue women and minorities; consequently, STEM environments are characterized by distrust and discouragement of women's activities and confidence in STEM professions that makes women think about leaving STEM professions (Clark et al., 2021). It is possible to cope with such differences by reassurance of female-characterized personalities, gender non-specificity in STEM advanced education. By telling girls why STEM subjects are necessary to study, illustrating how STEM subjects assist in the solution of real-life problems and invention of ideas (Merayo & Ayuso, 2023). However, the study also found that the availability of more female students and female teachers in STEM subjects had caused an improvement in STEM students' performance, particularly females.

Many factors highlighted in the given literature relate to gender disparities in STEM education. An analysis of available research reveals that variations in STEM degree completion correlate to variations in aspirations and attrition rates concerning gender, race/ethnicity, & parents' education (Costello et al., 2023). Also concerning the question-asking behavior in a virtual conference, the study to identify the problems that may prevent participants from asking questions found out that women posed fewer questions due to factors such

as negative feedback, lack of encouragement, and prejudice based on gender (Zhang et al., 2023). Early childhood educators' gender stereotypes can hinder girls' learning and interest in STEM education, including reasonable gender expectations and prejudices from the external environment regarding gender inequity in STEM play (Kiernan et al., 2022). Additionally, in robotics competitions girls dominate few teams and although all-girl teams struggle with actual robot construction, they outperform the other gender in other aspects namely communication and teamwork (Chan, 2022). Some of the measures taken to reduce gender prejudices involve encouraging the great role models among the female faculty members, ensuring the gender equity on campus, and motivating the girls to take up STEM courses (Kuchynka et al., 2022).

Measures for increasing gender representation in STEM disciplines should include educational policies and projects related to gender. Different papers note the necessity of the gender approach consideration in higher education to provide equal opportunities for both sexes (Ruel & Tajmel, 2023). Furthermore, there are global interventions aimed at dictating young people's involvement in STEM, with an emphasis being made on parity for girls (Prieto-Rodriguez et al., 2020). Due to the COVID-19 pandemic, the problem with representation of women in STEM, known as "leaky pipeline", remains topical and requires the adoption of specific changes in the policies and practices in order to enhance the presence of women in academic settings and research teams in STEM fields (Shah et al., 2021). Moreover, it establishes gender prejudice in the negative perception of women in STEM fields, thereby eradicating the ideal concept of intellectual diversity or meritocracy and national competitiveness; hence, there is a need for advocacy for the advancement of female participation STEM fields (Moss-Racusin et al., 2021).

METHOD

In this paper, the quantitative method to study gender dynamics within the settings of the ICT education is based on the big sample survey. The bibliometric data collected relating to ICT-integrated STEM programs included working on the influence of technology access, digital competency building, and gender-related barriers in engaging in ICT (Johnson et al., 2007). The meticulous methodology of conducting this study was comprised of intersectionality theory in examining gender identity as it relates to other demographic factors in an attempt to influence educational experiences with ICT using methodology designed by past gender and technology research (Cohoon & Aspray, 2006). Ethical aspects covered equal representation of both gender identities as well as expected confidentiality protocol of the participants as they share sensitive issues concerning discrimination at knowledge generation technology learning environment.

The present bibliometric analysis used an overall strategy to analyze the gender issue in **ICT integrated** STEM education literature. The papers were retrieved systematically from well-known web-based academic indexation, namely Scopus, published in the period of 2010 to 2024 focusing mainly on gender concerns in STEM education. To isolate relevant studies, strict research criteria were employed which looked at; peer-reviewed articles, English language articles, and articles that presented the publication year, authors, affiliations, funding, journal, citations, and subject specialization. The study encompassed multiple facets of analysis. Firstly, exploring temporal patterns in the published gender-focused STEM education literature; secondly, evaluating the academic reception of identified articles. Thirdly, comparing articles' distributions between and within journals, focusing on editorial specialization and journals' impact factors; fourthly, examining author affiliations to identify institutions and geographic regions contributing to the field. Finally, investigating the financial support sources acknowledged by authors to understand financial support of gender-related STEM education research. Moreover, the study noted sources that depict intended bias that came with using selected databases and restricting articles to those published in English only; this limited the scope of the study. Furthermore, citation thresholds and other factors were adjusted according to the professional expectations of the given discipline to provide the sound analysis and interpretation of citation data.

FINDINGS

The gaps identified in the bibliometric analysis show that the research in the gender and STEM education as well as research in computer science is a largely underdeveloped area with only 14 of the analyzed

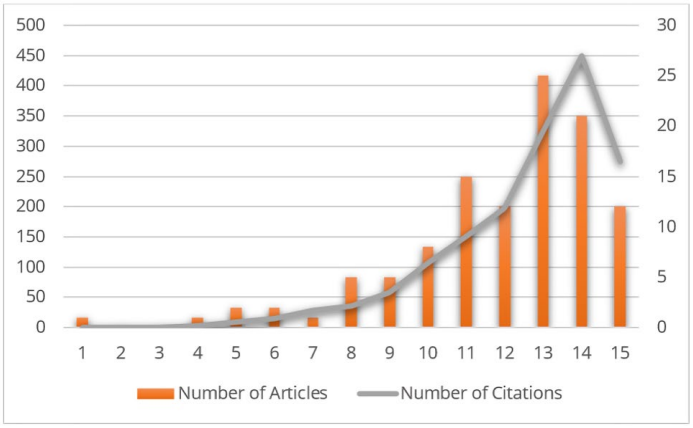

Figure 1. Number of articles and citations over the years (Source: Visual created by the authors)

documents on the topic of computer science, and this specific field involves the most intensive digitalization processes (Beyer et al., 2003). This underrepresentation is especially grave in the light of the fact that the most frequently used keywords are "STEM education" (99 copies) and "gender" (46 copies), but when it comes to technology-specific terms, they do not seem to be mentioned in the thematic territory as frequently. The temporal analysis reveals that the activity of the research reached its peak during 2022 when 25 articles and 325 citations were produced; however the latter point suggests that integration of the ICT education perspectives with respect to which the research was executed in itself is not to be found yet it could be considered that there is a research gap that requires a filling (Margolis & Fisher, 2002). Moreover, although all leading journals, namely Education Sciences and International Journal of Science Education take the top positions with 6 documents each, technology education journals are not represented well enough, which suggests that ICT education research might remain isolated on the periphery of gender and STEM research (Volman et al., 2005).

Publication and Citation Trends in the Field

There has been a continuously growing interest and citations in recent years. While there were no outputs concerning the study from 2010 and 2011, enhanced activity began during 2013. The least amount of research published in 2013 was one article, which was cited three times, meaning that the research has started on a very low note. Subsequent years showed a gradual rise: The number of articles reached maximum level by 2020 equaling to 15 and 152 citations signifying incorporation of the concept in the field. This increasing trend was sustained in 2023 where 21 articles received 450 citations thus showing that there is more attention and influence by scholars. However, it is also interesting to note that the year 2022 is highlighted with 25 articles and 325 citations which demonstrates the highest productivity point of this journal. By 2024, it is found that the number of articles had slightly declined to 12, while the total citation was still a fairly large value of 274. This proves that the topic of studying gender relations within STEM education continues to attract scholars' interest and has research significance using bibliometric analysis (**Figure 1**).

Authorship Patterns and Collaborations

The findings of this study depict a broad area of research with a rich variety of publications from scholars. Out of all the contributors, Barth, J. M., Perez-Felkner, L., and Roehrig, G. H., have written three articles that show that they are quite active and even hold leadership positions in their research. Now, given the relatively steady flow of contributions that these authors made to the studies, one could say that these scholars are committed to expanding gender research in STEM education. Further, and each author Chen, X. Y., Dare, E. A., Domingues, J. P. P., Eichen, L., Evans, T., Gomes, P. E. B. and Gore used two articles to contribute to the development of knowledge throughout this research (**Figure 2**).

These working patterns support the interdisciplinary approach and mutual cooperation among the authors occupied in research and provide a wide perspective in investigating the gender processes occurring in STEM education. In this regard, the papers' authorship diversities and collaborations not only enhance

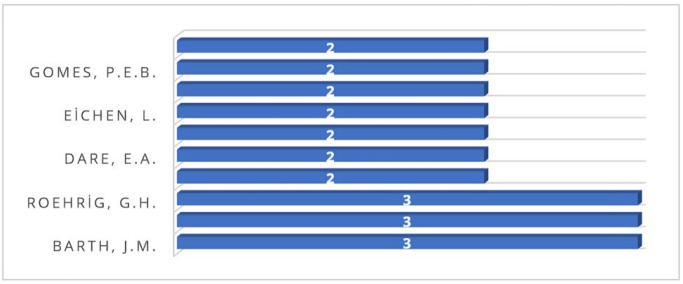

Figure 2. Number of articles per author (Source: Visual created by the authors)

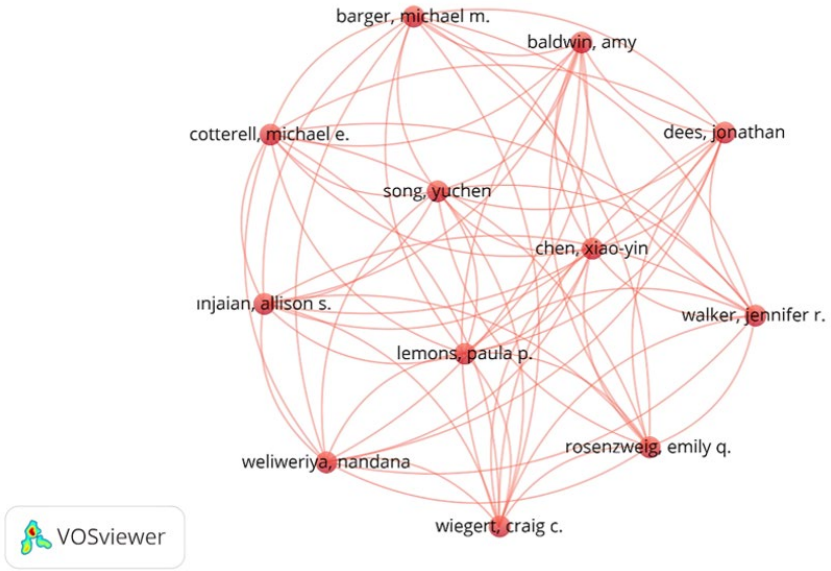

Figure 3. Author networks (Source: Created by the authors using software tools)

Table 1. Number of keywords in the articles

Keywords	Number of keywords
STEM education	99
Gender	46
Gender differences	15
Gender gap	8
Gender disparity	4
Total	173

scholarly conversations enriching the extant literature but also enhances the development of a solid foundation (**Figure 3**).

Keyword Analysis

The analysis of the existing keywords provides a better understanding of the thematic field's focus and the range of covered topics. If we look at the intensity of the use of certain terms, it can be noted that the most frequently used terms are as follows: Out of these, STEM education is used prominently 99 times and is the key area of study for the researchers. This is an indication of a large number of studies with intention to improving educational practices and results in STEM learning areas. Furthermore, the term "gender" is used frequently with an impressive total of 46 hits, a fact that testifies to researchers' preoccupation with the gender question and the effects that gender might have on STEM regarding participation, performance, and future professional paths. The next most frequently used keywords are "gender differences" which comes with 15 hits, "gender gap" 8 while "gender disparity "only comes with 4 hits, that implying that the studies done on STEM courses pay attention to the differences and inconveniences faced by male and female gender groups (**Table 1**).

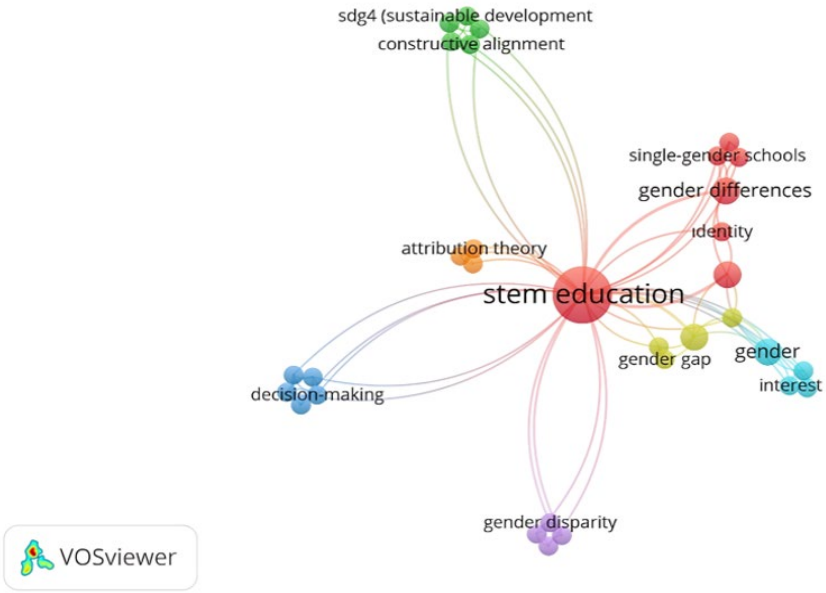

Figure 4. Keywords networks (Source: Created by the authors using software tools)

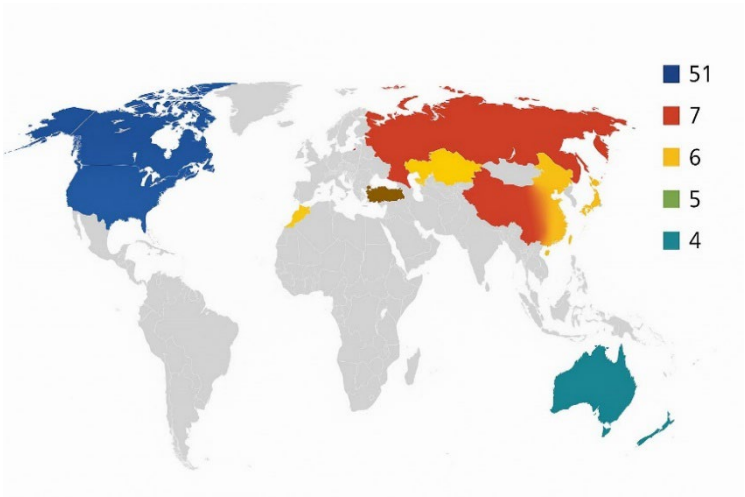

Figure 5. Number of articles per country (Source: Visual created by the authors)

Altogether, these keywords help to form a more diversified picture of what is still a rather limited and fragile change in general for STEM when it comes to gender equity, but what is still a very problematic and patriarchal present for girls in STEM education. Thus, this keyword analysis not only represents up-to-date knowledge production but also provides a reference point for future research and policy (**Figure 4**).

International Perspective: Regional Contributions

The results confirm that there is no country domination and contributors spread over different territories. The USA appears as the leading nation with 51 articles, which stand for major activity in this country in researching gendered processes within STEM education. This solid input from the USA can attest to the USA's proper development of academic resources and their proper commitment in the cause of elevating women's rights and the importance of their representation in STEM-related careers. After the USA, the Russian Federation and Australia released 7 and 6 papers, respectively, which implies a vigorous involvement along with burgeoning academic concern comprehending these areas. In the same manner, China and Turkey provided five documents each in their purposeful search for gender issues under the educational system. Canada, Israel, Mexico, Italy, and Spain had 3-4 documents each which pointed out that the global communities have actively contributed to the development of new knowledge on the gender issue in STEM education (**Figure 5**).

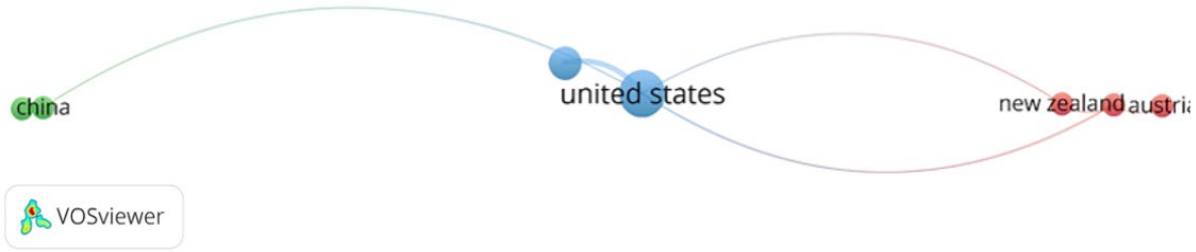

Figure 6. Countries network (Source: Created by the authors using software tools)

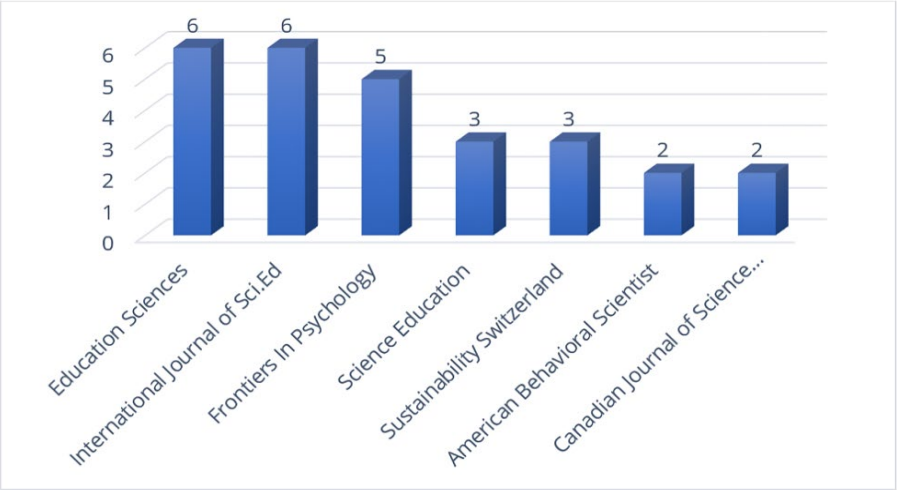

Figure 7. Top journals and number of articles (Source: Visual created by the authors)

This perspective in addition to diversifying the approaches and viewpoints also enhances the cooperation on how global issues can be solved and how equal opportunities in STEM areas can be provided. The level of participation differs across the regions, and this serves to highlight the need to bring together scholars from different countries to combat the issues affecting female students, so as to enhance equity across the globe concerning STEM education (**Figure 6**).

Top Journals in the Field: Publication Patterns and Impact

An evaluation of trends in publishing as displayed in the leading periodicals produces essential information concerning the communication of gender in STEM education research. Considering the total amount of publications and focusing on the journals containing most of the documents, the most important ones proved to be Education Sciences and the International Journal of Science Education containing 6 documents in total. These journals remain major vehicles for researchers to input their common knowledge, new ideas, and research findings on gender equity in STEM education. Directly next comes Frontiers in Psychology that issued 5 papers, proving its focus on contributing to the increase in knowledge of the psychological factors affecting STEM's gender gap. Science Education and Sustainability Switzerland are both well immersed in the implementation of sustainable and inclusive educational practices across various STEM fields, and all of them have 3 documents. Furthermore, 2 documents can be sourced from the American Behavioral Scientist and the Canadian Journal of Science, Mathematics and Technology Education to prove their attempt at a discussion about gender in STEM education (**Figure 7**). The publication patterns highlighted in these top journals indicate their combined endeavors in transforming and sharing the knowledge required in policymaking and practice. These patterns emphasized also in charting future research directions towards the achievement of gender equality and diversity in STEM education around the world. Besides, this analysis demonstrates the rich research interest and the ongoing collaboration among researchers, educators, and policymakers in the dissemination of crucial information on matters related to STEM fields inclusiveness (**Figure 8**).

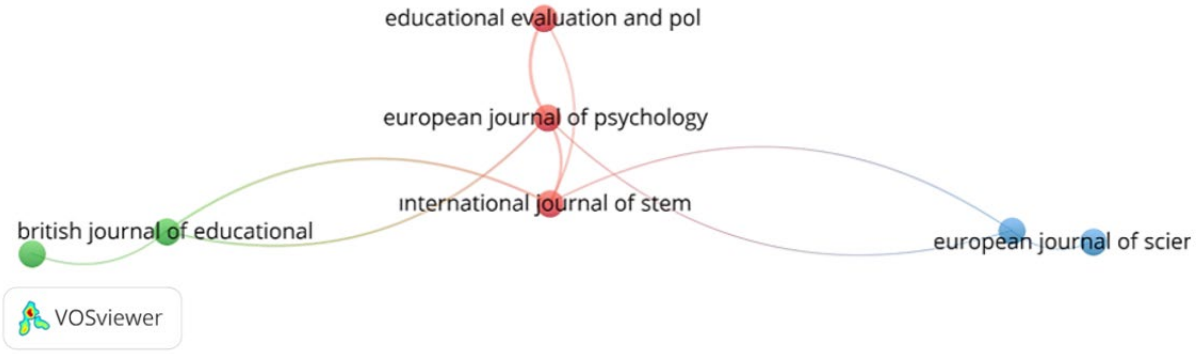

Figure 8. Journal networks (Source: Created by the authors using software tools)

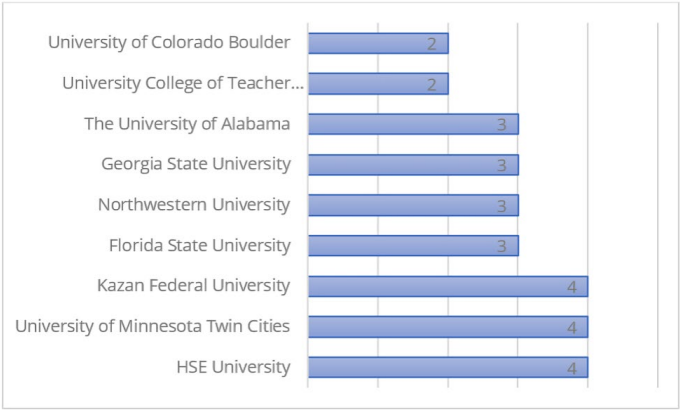

Figure 9. Number of articles per affiliation (Source: Visual created by the authors)

Leading Institutions in the Field: Contribution and Collaboration

A review of the institution's contributions shows that most key academic bodies have actively participated and contributed towards the research initiative. HSE University and University of Minnesota Twin Cities have published the largest number of documents equal to four documents each, which indicates their significant research activity and the role in developing knowledge in the field of gender relations in STEM education. Due to their academic authority, these institutions have significant roles in providing discourse and policymaking towards gender mainstreaming; the faculties are endowed with research tools to discuss various angles on gender disparities within STEM education. Close behind with three documents each are Florida State University, Northwestern University, Georgia State University, and the University of Alabama, showing that these institutions are very involved and are working on pertinent concerns regarding gender stereotypes and diversity in STEM fields. Also, the University College of Teacher Education Styria and University of Colorado Boulder each contribute to 2 documents, proving that they are institutions working on cross-disciplinary approaches and supporting equality for male and female students in STEM education (**Figure 9**). Thus, the diversified offer of institutional contributions represents a global and collective approach in the furthering of knowledge, ideas, and policies when it comes to gender diversity in STEM arenas. The activities of these prominent institutions not only expand the body of knowledge but also help design fair conditions for individuals of both genders and other minorities engaged in STEM fields for study and work around the world (**Figure 10**).

Top Funding Agencies and their Contributions

The funding sources indicate the high concern of various agencies that aim at extending the knowledge on the existence of gender in STEM disciplines. Here, the most active funding and inspirational supporter is the National Science Foundation (NSF) with 17 documents, strengthening gender mainstreaming, school practices, and workforce's encouragement to engage in STEM careers. Just second to NSF, the Directorate for Education and Human Resources funds 6 documents signifying continued actions toward enhancing STEM

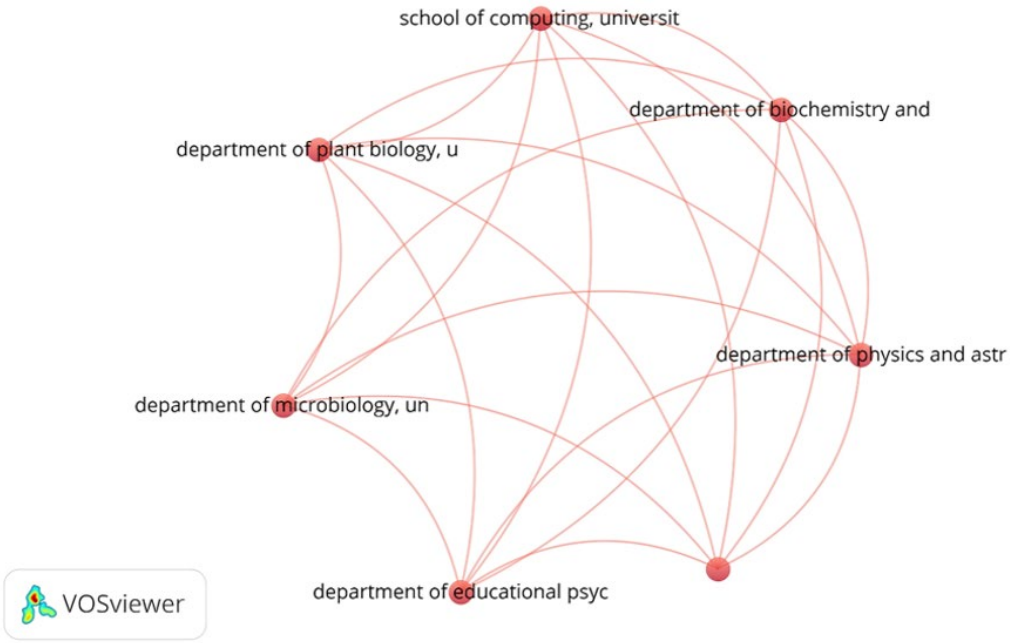

Figure 10. Networks of affiliations and clustering analysis (Source: Created by the authors using software tools)

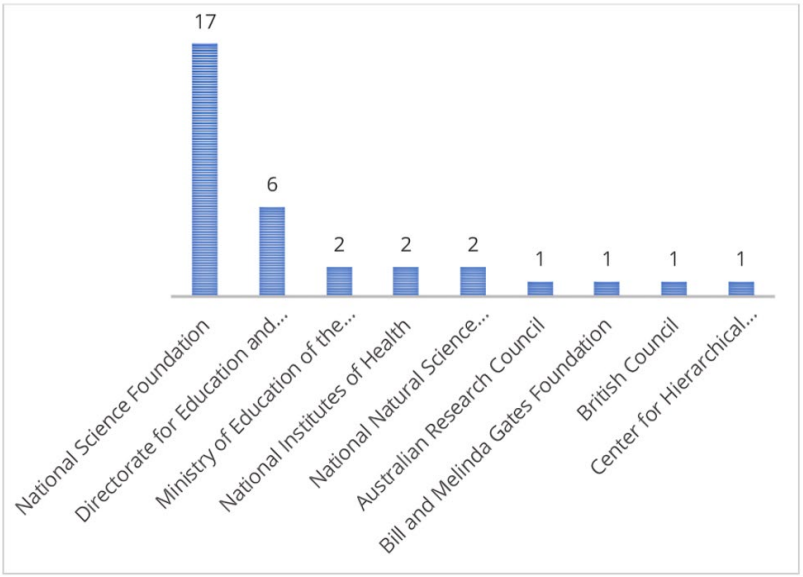

Figure 11. Number of articles per funding sponsors (Source: Visual created by the authors)

education and its propagation to promote additional measures toward narrowing gender disparities in STEM learners. The Ministry of Education of the People's Republic of China, National Institutes of Health and the National Natural Science Foundation of China, fund and support 2 each to ensure that gender issues will remain in the Forefront of discussions on educational system and science advancement. In addition, there was a constant revelation of 1 sponsored document from the Australian Research Council, Bill & Melinda Gates Foundation, British Council as well as the Center for Hierarchical Manufacturing at NSF (**Figure 11**). They stipulate that they fund intersectoral studies and enhance female parity in STEM for global versions. These funding agencies are also engaged in other significant roles apart from the sponsorship of the type of research that aims at reducing gender bias and ensuring that all anyone who wants to pursue careers and education within STEM sites is given equal opportunities. Combined with one another, their actions speak to a shared intent to engage and help in the resolution of complex problems as well as to disclose opportunities of various STEM groups and educational environments.

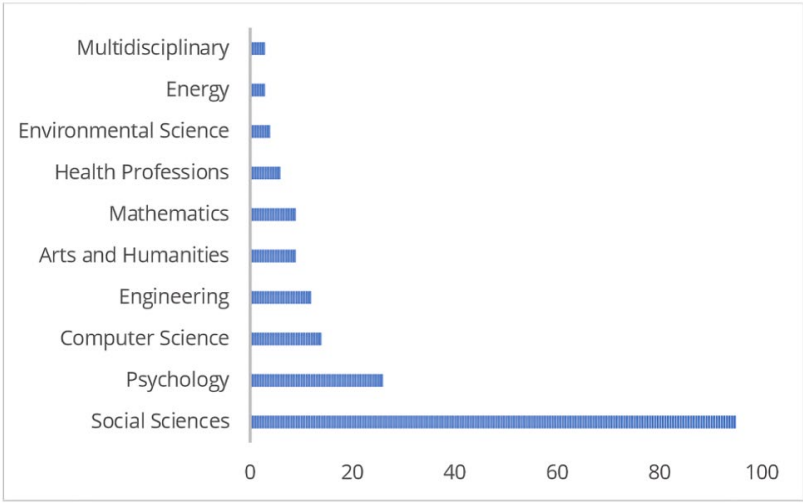

Figure 12. Number of articles on subject areas (Source: Visual created by the authors)

Subject Areas

In an analysis of the distribution of documents related to the identified themes and keywords it is clear that gender issues in STEM education are addressed in a diverse way in the various disciplines. Social sciences is the most represented with 95 articles, which confirms that the topic of gender equality in STEM is actively investigated and discussed in terms of numerous socio-cultural factors and their impacts. This is followed by psychology with 26 documents, showing that psychology has a strong contribution to the study of various aspects of psychological nature regarding gender within STEM disciplines that include; identity, stereotyping and career interests. Compared to the previous year, computer science and engineering submitted 14 and 12 documents, respectively, to address the need to examine gender concerns in the areas of technical expertise. Specifically, arts and humanities and mathematics consist of only 9 documents each, illustrating the necessity of intertwining cultural and historical approaches to the analysis of gender in STEM education with methods of quantifying the existing gaps in students' achievements quantitatively. This category consists of 6 documents as interest to gender topic in Health Professions, which is a part of STEM fields, has been rising. Energy, which is relevant to the project and gender has 3 documents while environmental science has a contribution of 4 documents. Further, multidisciplinary studies involves 3 documents; this shows how scholars have adopted the Multidisciplinary in addressing gender equity concerns in STEM education while interrelating different fields. The above-discussed areas of focus show the cross-disciplinary nature of gender issues in STEM to require inter-professional solutions and research towards boosting smart diversity and parity across STEM fields and careers (**Figure 12**).

DISCUSSION AND CONCLUSION

The correlations provided by the bibliometric report point out a pertinent necessity of strengthened integration of the ICT education vision in the sphere of gender and STEM research, as its trace is visible in the frequency of minuscule coverage of computer science (14 documents) in the collection compared to social sciences (95 documents). Such an imbalance implies that social and psychological dimensions of gender in STEM have gained sufficient attention to the point that the technological ones will appear undeveloped and can constrain our knowledge about the ways in which digital literacy and computational thinking will become an intersection of gender equity issues (Wang & Degol, 2017). The implied ascendancy of the funding opportunities of such agencies as the NSF (17 documents) creates possibilities of promoting further and more ICT-oriented research activities that will specifically consider the gender inequity in technological educational settings (Trauth et al., 2004). Since the research area is experiencing a long-term growth (with 450 citations in 2023), there are high prospects of an increase in the academic discussion through the integration of ICT educational systems that can help fill the gap between traditional STEM disciplines and new digital skills needed to prepare students in the 21st century to be ready to work (Vekiri & Chronaki, 2008).

The findings thus depict enhanced active participation in the last couple of years. Although the level of activity was insignificant in 2010 and 2011, nothing was published during those years, it rose to one article with three citations in 2013. This was the beginning of a continuous increase, later years of which show a gradation increase in terms of research output. As depicted by the figure in the subsequent section, the number of articles reached the highest level by 2020, where it reached 15 with a total citation of 152 showing will incorporation of gender studies into STEM education. This momentum was similarly sustained in 2023 with 21 articles achieving 450 citation implying growing interest of scholars in this research. Peculiarly, productivity was at its peak in 2022 with a total of 25 articles and 325 citations of these articles, in 2024 the article quantity declined slightly to 12 articles, but the number of citations reached 274. This pattern also shows that gender relations remain an important aspect, thereby contributing to the relevance of research, especially in STEM education (Merayo & Ayuso, 2023; Tandrayen-Ragoobur & Gokulsing, 2022).

The articles produced in the field of the study link to a wide array of works presenting enhancements from many scholars. Finally, from the authors' perspective, one can mention that Barth, J. M., Perez-Felkner, L., and Roehrig, G. H are the most active in publishing and thus should be recognized as leaders in this field. Besides, other prolific authors such as Chen, X. Y., Dare, E. A., and Domingues, J. P. P. have also published two articles each in this field that depict this as a team-up and cross-disciplinary work. Such patterns of cooperation among authors contribute to the development of the interdisciplinary understanding of gender relations in STEM education and enhance the theoretical discourse, thus providing a sound groundwork for further research (Khushk et al., 2023; Zhan et al., 2022).

Keyword analysis supplements the definition of this field's thematic direction. The bait "STEM education" was mentioned 99 times as the focus on enhancing educational practices in STEM was considered critical. This is then followed by "gender" with the 46, clearly showing active researcher interest in the field of gender and its relation to STEM interest and success. Such specified terms that were used quite often are 'gender differences' which occurs 15 times, gender gap, which occurs eight time, and "gender disparity" which is used four times; there is thus more focus on trying to solve or address gender issues in STEM education. This keyword analysis helps to give a wide perspective of the field, demonstrating both the accomplishments and problems, with the latter being recent cases of patriarchy that limit girls in STEM (Hasenhütl et al. 2024; LaForce et al., 2019; Wright & Delgado, 2023).

Globally, the findings indicate that there is no country that leads the others in research as contribution is from so many countries. The USA has the highest number of articles with 51, which might be due to enhanced academic facilities and the nation's focus on parity for men and women in the STEM field. The Russian Federation and Australia also follow the USA with 7 and 6, respective papers. Other key contributors for the reviewed documents include China = 5, Turkey = 5, Canada = 3, Israel = 3, Mexico = 3, Italy = 3, and Spain= 3. It supports the idea of this paper that gender issues are studied in many countries and global collaboration is necessary (Amirtham & Kumar, 2023; Zhan et al., 2022).

Bibliometric profiles of key journals holding significant information in the communication of gender in STEM education were as follows: Six documents in this area belong to "education sciences" and the "International Journal of Science Education" as these to journals mostly publish scholarly work on this topic. Out of five papers, one of the journals entitled "Frontiers in Psychology" yields the psychological aspect of gender disparities in STEM. The three documents in "Science Education" and "Sustainability Switzerland" point out the implementation of sustainable and inclusive actions in the STEM field. These publication patterns are suggestive of attempts by the researchers to champion change on the policy and practice with a view to enhancing gender equity in STEM (Akhmedova et al., 2023; Ishmuradova et al., 2023).

It is also important to highlight the institutional contribution, HSE University submitted four documents while the University of Minnesota Twin Cities contributed similarly. These institutions play a significant role in defining the issues and solving problems regarding gender mainstreaming within STEM education. Other active institutions include Florida State University, Northwestern University, Georgia State University, and the University of Alabama with three documents; this shows that their institutions are also committed to the elimination of gender stereotypes and encouragement of diversity in STEM (Ruel & Tajmel, 2023; Wright & Delgado, 2023).

The encouragement from funding agencies plays a big role in the progression of this research. Taking the primary position is the NSF, which is involved in 17 documents, pointing to its leading part in the struggle for female representation in STEM. Six documents are presented in the section of the Directorate for Education and Human Resources and it shows that an attempt has been made to further improve STEM education. Other funders are Ministry of Education of the People's Republic of China and National Institutes of Health each provided findings for two documents. These agencies' input is essential in influencing the generation of research and policy goals to tackle the gender stereotype and promote equal opportunity in STEMS education (Hyde, 2022).

Lastly, the discovery of the spread of the research in various disciplines underlines the complex perspectives of the gender issues in STEM. Social sciences are dominating this list with 95 articles, which is again influenced by the special attention paid to the socio-cultural perspective of the phenomenon. Psychology takes second place with 26 documents looking at issues in identity and stereotyping. Out of the 49 documents relating to gender, computer science and engineering, 14 and 12 papers lay emphasis on the technical aspects of gender issues. Other disciplines that include arts & humanities, mathematics, health professions, energy, environmental science & multidisciplinary studies also have some representation showing the need and collaboration that is needed to solve the gender dilemma in STEM education. These are significant interdisciplinary areas of study that are critical to the creation of inclusive solutions across STEM disciplines (Maji et al., 2023; Sona et al., 2022).

Implications for Future Research Directions

The argumentation of the findings leads to the following potential lines of thinking for future research. So, to know the effect of gender-focused interventions in STEM education, more longitudinal research studies need to be conducted. Gender studies conducted in combination with other social categories like race, ethnicity, and socioeconomic status are very important. Furthermore, extending the focus on the nature and the impact of early years education, out-of-school contexts and other environmental factors for STEM-related beliefs may prove insightful. Cross-cultural comparison of practices and policies can enhance the learning process in an attempt to establish standard or at least unique, procedures, and strategies for enhancing gender equality across the world. Therefore, the bibliometric analysis presented in this paper emphasizes the developments of the gender studies in STEM education and essential issues that require further research. This study presents an extensive approach by determining trends, contributors, and themes in order to create a foundation to help in future research. Thus, it is high time gender inequalities in STEM education are redressed in order to also ensure that the society and talent pool contain a diverse and broad-based capable of handling future problems. Further investigation and studying the cooperation within disciplines and countries is crucial for making the changes that would help people have equal chances in STEM.

Further research will also prove helpful in the analysis of gender-sensitive programs regarding STEM learning where the completion rates will be compared at various times of the year. Therefore, there is a need to advance intersectional approaches regarding the integrated roles associated with gender together with race/ ethnicity and class positions and disability statuses. Such an approach can be more informative for identifying the factors enhancing or limiting students' engagement in STEM activities among the targeted audiences because it can indicate factors that are connected with particular groups. Subsequently, there is still a need for gathering more data that relates to effects of early education and other kinds of learning which a child undergoes, as well as other child development initiatives such as after school activities and the influence that family has on learning. The impact on young learners' interest, self-efficacy and attitudes to STEM education and learning, such settings should be researched through studies that may reveal further intervention points. To further confirm this assertion, it is relevant to evaluate the outcomes of policy interventions in the subjects of gender equality for STEM and other institutional measures. Thus, cross-cultural and cross-system education comparative research can offer improved views, experiences, best practices, and models to follow globally. Thus, further research continuing in the multicultural aspect is needed. The information on how different countries and cultures fight gender stereotyping and imbalance of female representation in STEM may disclose some effective practices that can be replicated around the globe. These tools or technologies must make an evaluation of their contribution towards increasing the participation levels and possibly the closing of the gender gaps.

In conclusion, by outlining these future directions, scholars simply contribute to the advancement of gaps of knowledge, improve the efficacy of interventions, and participate in the ongoing effort of creating a more equitable STEM culture. Gender equity is not simply civil work, but it is good for business and needed to address other global challenges.

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REFERENCES

Achtzehn, S., Treanor, L., & Amess, K. (2023). Do enterprise education competitions have gendered outcomes amongst STEM early-career researchers? *International Small Business Journal, 41*(8), 801–824. https://doi.org/10.1177/02662426231158281

Akhmedova, M. G., Ibragimov, G. I., Kryukova, N. I., Galchenko, N. A., Lutskovskaia, L. Y., Sizova, Z. M., & Minkin, M. R. (2023). Uncovering patterns and trends in online teaching and learning for STEM education. *Contemporary Educational Technology*, *15*(3), Article ep444. https://doi.org/10.30935/cedtech/13363

Amirtham S, N., & Kumar, A. (2023). The underrepresentation of women in STEM disciplines in India: A secondary analysis. *International Journal of Science Education*, *45*(12), 1008–1031. https://doi.org/10.1080/09500693.2023.2179901

Ashlock, J., Stojnic, M., & Tufekci, Z. (2021). Gender differences in academic efficacy across STEM fields. *Sociological Perspectives, 65*(3), 555–579. https://doi.org/10.1177/07311214211028617

Beyer, S., Rynes, K., Perrault, J., Hay, K., & Haller, S. (2003). Gender differences in computer science students. *ACM SIGCSE Bulletin, 35*(1), 49–53.

Bowman, N. A., Logel, C., LaCosse, J., Jarratt, L., Canning, E. A., Emerson, K. T. U., & Murphy, M. C. (2022). Gender representation and academic achievement among STEM-interested students in college STEM courses. *Journal of Research in Science Teaching, 59*(10), 1876–1900. https://doi.org/10.1002/tea.21778

Chan, R. C. H. (2022). A social cognitive perspective on gender disparities in self-efficacy, interest, and aspirations in science, technology, engineering, and mathematics (STEM): The influence of cultural and gender norms. *International Journal of STEM Education, 9*, Article 37. https://doi.org/10.1186/s40594-022-00352-0

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), 1–35. https://doi.org/10.1037/bul0000052

Chiang, F., Tang, Z., Zhu, D., & Bao, X. (2023). Gender disparity in STEM education: Survey research on girl participants in World Robot Olympiad. *International Journal of Technology and Design Education, 34*, 629–646. https://doi.org/10.1007/s10798-023-09830-0

Clark, S. L., Dyar, C., Inman, E. M., Maung, N., & London, B. (2021). Women's career confidence in a fixed, sexist STEM environment. *International Journal of STEM Education, 8*, Article 56. https://doi.org/10.1186/s40594-021-00313-z

Cohoon, J. M., & Aspray, W. (Eds.). (2006). *Women and information technology: Research on underrepresentation*. MIT Press. https://doi.org/10.7551/mitpress/9780262033459.001.0001

Costello, R. A., Salehi, S., Ballen, C. J., & Burkholder, E. (2023). Pathways of opportunity in STEM: Comparative investigation of degree attainment across different demographic groups at a large research institution. *International Journal of STEM Education, 10*, Article 46. https://doi.org/10.1186/s40594-023-00436-5

Daniela, L., Kristapsone, S., Kraģe, G., Belogrudova, L., Vorobjovs, A., & Krone, I. (2022). Searching for pedagogical answers to support STEM learning: Gender perspective. *Sustainability, 14*(21), Article 14598. https://doi.org/10.3390/su142114598

Ferati, M., Demukaj, V., Kurti, E., Mörtberg, C., Shahrabi, K., & Mustafa, M. K. (2023). Gender stereotypes and women participation in STEM fields in the Western Balkans: A scoping review. *Academic Journal of Interdisciplinary Studies, 12*(2), Article 228. https://doi.org/10.36941/ajis-2023-0044

Guevara-Ramírez, P., Ruiz-Pozo, V. A., Cadena-Ullauri, S., Salazar-Navas, G., Bedón, A. A., V-Vázquez, J. F., & Zambrano, A. K. (2022). Ten simple rules for empowering women in STEM. *PLoS Computational Biology, 18*(12), Article e1010731. https://doi.org/10.1371/journal.pcbi.1010731

Hagan, C. O., O'Connor, P., Myers, E. S., Baisner, L., Apostolov, G., Topuzova, I., Saglamer, G., Tan, M. G., & Çağlayan, H. (2016). Perpetuating academic capitalism and maintaining gender orders through career practices in STEM in universities. *Critical Studies in Education, 60*(2), 205–225. https://doi.org/10.1080/17508487.2016.1238403

Hasenhütl, S., Luttenberger, S., Macher, D., Eichen, L., Eglmaier, M. T. W., & Paechter, M. (2024). Empowering educators: A training for pre-service and in-service teachers on gender-sensitive STEM instruction. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(6), Article em2452. https://doi.org/10.29333/ejmste/14590

Idrizi, E., Filiposka, S., & Trajkovikj, V. (2023). Gender impact on STEM online learning- a correlational study of gender, personality traits and learning styles in relation to different online teaching modalities. *Multimedia Tools and Applications, 82*(19), 30201–30219. https://doi.org/10.1007/s11042-023-14908-x

Ishmuradova, A. M., Svintsova, M. N., Kondakchian, N. A., Zaitseva, N. A., Sokolova, N. L., & Khairullina, E. R. (2023). A bibliometric overview of science communication research in STEM education. *Online Journal of Communication and Media Technologies*, *13*(4), Article e202341. https://doi.org/10.30935/ojcmt/13415

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research, 1*(2), 112–133. https://doi.org/10.1177/1558689806298224

Joseph, J. (2023). Factors that impact the persistence of women in STEM higher education: A systematic literature review. *Research Square*. https://doi.org/10.21203/rs.3.rs-2754168/v1

Khushk, A., Zhiying, L., Yi, X., & Zengtian, Z. (2023). Technology innovation in STEM education: A review and analysis. *IJERI: International Journal of Educational Research and Innovation*, (19), 29–51. https://doi.org/10.46661/ijeri.7883

Kiernan, L., Walsh, M., & White, E. (2022). Gender in technology, engineering and design: Factors which influence low STEM subject uptake among females at third level. *International Journal of Technology and Design Education, 33*(2), 497–520. https://doi.org/10.1007/s10798-022-09738-1

Koul, R. B., McLure, F. I., & Fraser, B. J. (2021). Gender differences in classroom emotional climate and attitudes among students undertaking integrated STEM projects: A Rasch analysis. *Research in Science & Technological Education, 41*(3), 1051–1071. https://doi.org/10.1080/02635143.2021.1981852

Kuchynka, S. L., Eaton, A., & Rivera, L. M. (2022). Understanding and addressing gender-based inequities in STEM: Research synthesis and recommendations for U.S. K-12 education. *Social Issues and Policy Review, 16*(1), 252–288. https://doi.org/10.1111/sipr.12087

LaForce, M., Zuo, H., Ferris, K., & Noble, E. (2019). Revisiting race and gender differences in STEM: Can inclusive STEM high schools reduce gaps? *European Journal of STEM Education*, *4*(1), Article 08. https://doi.org/10.20897/ejsteme/5840

Leibnitz, G. M., Peters, J. W., Campbell-Montalvo, R., Metcalf, H., Putwen, A. L., Gillian-Daniel, D. L., Sims, E. L., & Segarra, V. A. (2022). Refining a DEI assessment tool for use in optimizing professional STEM societies for gender equity. *Frontiers in Sociology, 7*. https://doi.org/10.3389/fsoc.2022.755372

Maji, S., Mitra, S., & Asthana, M. K. (2023). 'Treading the no woman's land': The gender-STEM dynamics in higher education in premier institutions of India. *European Journal of Engineering Education, 48*(3), 422–447. https://doi.org/10.1080/03043797.2023.2168518

Maloshonok, N. G., Shcheglova, I. A., Vilkova, K. A., & Abramova, M. O. (2022). How to attract women in STEM and help them become successful: The review of practices of overcoming gender stereotypes. *Vyssee Obrazovanie V Rossii, 31*(11), 63–89. https://doi.org/10.31992/0869-3617-2022-31-11-63-89

Manly, C. A., Wells, R. S., & Kommers, S. (2018). The influence of STEM definitions for research on women's college attainment. *International Journal of STEM Education, 5*, Article 45. https://doi.org/10.1186/s40594-018-0144-1

Margolis, J., & Fisher, A. (2002). *Unlocking the clubhouse: Women in computing*. MIT Press.

Merayo, N., & Ayuso, A. (2023). Analysis of barriers, supports and gender gap in the choice of STEM studies in secondary education. *International Journal of Technology and Design Education, 33*(4), 1471–1498. https://doi.org/10.1007/s10798-022-09776-9

Miralles-Cardona, C., Kitta, I., & Cardona-Moltó, M. (2023). Exploring pre-service STEM teachers' capacity to teach using a gender-responsive approach. *Sustainability, 15*(14), Article 11127. https://doi.org/10.3390/su151411127

Moè, A., Hausmann, M., & Hirnstein, M. (2020). Gender stereotypes and incremental beliefs in STEM and non-STEM students in three countries: Relationships with performance in cognitive tasks. *Psychological Research, 85*(2), 554–567. https://doi.org/10.1007/s00426-019-01285-0

Moss-Racusin, C. A., Pietri, E. S., Van Der Toorn, J., & Ashburn-Nardo, L. (2021). Boosting the sustainable representation of women in STEM with evidence-based policy initiatives. *Policy Insights from the Behavioral and Brain Sciences, 8*(1), 50–58. https://doi.org/10.1177/2372732220980092

Ortiz-Martínez, G., Vázquez-Villegas, P., Ruiz-Cantisani, M. I., Delgado-Fabián, M., Conejo-Márquez, D. A., & Membrillo-Hernández, J. (2023). Analysis of the retention of women in higher education STEM programs. *Humanities & Social Sciences Communications, 10*, Article 101. https://doi.org/10.1057/s41599-023-01588-z

Pasha-Zaidi, N., & Afari, E. (2016). Gender in STEM education: An exploratory study of student perceptions of math and science instructors in the United Arab Emirates. *International Journal of Science and Mathematical Education, 14*(7), 1215–1231. https://doi.org/10.1007/s10763-015-9656-z

Peña, M., Olmedo-Torre, N., De Les Valls, E. M., & Lusa, A. (2021). Introducing and evaluating the effective inclusion of gender dimension in STEM higher education. *Sustainability, 13*(9), Article 4994. https://doi.org/10.3390/su13094994

Prieto-Rodriguez, E., Sincock, K., & Blackmore, K. (2020). STEM initiatives matter: Results from a systematic review of secondary school interventions for girls. *International Journal of Science Education, 42*(7), 1144–1161. https://doi.org/10.1080/09500693.2020.1749909

Rincón, B. E., & George-Jackson, C. E. (2016). Examining department climate for women in engineering: The role of STEM interventions. *Journal of College Student Development, 57*(6), 742–747. https://doi.org/10.1353/csd.2016.0072

Ruel, S., & Tajmel, T. (2023). At the intersection of science, technology, engineering, and mathematics and business management in Canadian higher education: An intentional equity, diversity, and inclusion framework. *Gender, Work and Organization, 31*(3), 821–850. https://doi.org/10.1111/gwao.13035

Sarabi, Y., & Smith, M. (2023). Gender diversity and publication activity–An analysis of STEM in the UK. *Research Evaluation, 32*(2), 321–331. https://doi.org/10.1093/reseval/rvad008

Schmader, T. (2023). Gender inclusion and fit in STEM. *Annual Review of Psychology, 74*(1), 219–243. https://doi.org/10.1146/annurev-psych-032720-043052

Shah, A., Lopez, I., Surnar, B., Sarkar, S., Duthely, L. M., Pillai, A., Salguero, T. T., & Dhar, S. (2021). Turning the tide for academic women in STEM: A post-pandemic vision for supporting female scientists. *ACS Nano, 15*(12), 18647–18652. https://doi.org/10.1021/acsnano.1c09686

Simon, R. M., Wagner, A., & Killion, B. (2016). Gender and choosing a STEM major in college: Femininity, masculinity, chilly climate, and occupational values. *Journal of Research in Science Teaching, 54*(3), 299–323. https://doi.org/10.1002/tea.21345

Sona, A. J., Laboy Santana, J., & Saitta, E. K. (2022). Looking through a prism: A systematic review of LGBTQ+ STEM literature. *Journal of Chemical Education*, *100*(1), 125–133. https://doi.org/10.1021/acs.jchemed.2c00391

Steffen, A., Dodiya, J., Heinisch, C., Hess, C., Kunz, S., Rebholz, S., Schlömer, I., Vaas, S., & Rippich, K. (2023). An exploration of critical incidents impacting female students' attitude towards STEM subjects. *International Conference on Gender Research, 6*(1), 215–223. https://doi.org/10.34190/icgr.6.1.994

Tandrayen-Ragoobur, V., & Gokulsing, D. (2022). Gender gap in STEM education and career choices: What matters? *Journal of Applied Research in Higher Education*, *14*(3), 1021–1040. https://doi.org/10.1108/JARHE-09-2019-0235

Trauth, E. M., Quesenberry, J. L., & Yeo, B. (2004). The influence of demographic characteristics on the career choices of women in the IT workforce. *ACM SIGMIS Database, 35*(4), 58–75.

Vekiri, I., & Chronaki, A. (2008). Gender issues in technology use: Perceived social support, computer self-efficacy and value beliefs, and computer use beyond school. *Computers & Education, 51*(3), 1392–1404. https://doi.org/10.1016/j.compedu.2008.01.003

Verdugo-Castro, S., Sánchez-Gómez, M. C., & García-Holgado, A. (2022). University students' views regarding gender in STEM studies: Design and validation of an instrument. *Education and Information Technologies, 27*(9), 12301–12336. https://doi.org/10.1007/s10639-022-11110-8

Volman, M., van Eck, E., Heemskerk, I., & Kuiper, E. (2005). New technologies, new differences. Gender and ethnic differences in pupils' use of ICT in primary and secondary education. *Computers & Education, 45*(1), 35–55. https://doi.org/10.1016/j.compedu.2004.03.001

Wang, M. T., & Degol, J. L. (2017). Gender gap in science, technology, engineering, and mathematics (STEM): Current knowledge, implications for practice, policy, and future directions. *Educational Psychology Review, 29*(1), 119–140. https://doi.org/10.1007/s10648-015-9355-x

Wang, S. (2023). Exploring early childhood educators' perceptions and practices towards gender differences in STEM play: A multiple-case study in China. *Early Childhood Education Journal, 52*, 1121–1134. https://doi.org/10.1007/s10643-023-01499-3

Wright, G. W., & Delgado, C. (2023). Generating a framework for gender and sexual diversity-inclusive STEM education. *Science Education, 107*(3), 713–740. https://doi.org/10.1002/sce.21786

Zhang, J., Torchet, R., & Julienne, H. (2023). Gender-based disparities and biases in science: An observational study of a virtual conference. *PLoS ONE, 18*(6), Article e0286811. https://doi.org/10.1371/journal.pone.0286811