STUDY

Requested by the FEMM committee

Education and employment of women in science, technology and the digital economy, including AI and its influence on gender equality

Policy Department for Citizens' Rights and Constitutional Affairs
Directorate-General for Internal Policies
PE 651.042- April 2020

EN

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Abstract

This study, commissioned by the European Parliament's Policy Department for Citizens' Rights and Constitutional Affairs at the request of the FEMM Committee, provides evidence that there is still gender bias and inequality in STEM (Science, Technology, Engineering, Mathematics) fields and the digital sector (e.g., digital technologies, Computer Science, Information Technology, Information and Communication Technology, Artificial Intelligence, cybersecurity). This document, prepared at the request of the FEMM Committee (Policy Department for Citizens' Rights and Constitutional Affairs, Directorate-General for Internal Policies), is intended to provide an up-to-date literature review on the current status of women's education and employment in STEM fields and the digital sector. In so doing, the corresponding trajectories are examined, from the primary education level up to the employment level, in an attempt to identify obstacles and bottlenecks that prevent gender parity. Finally, suggestions for future research, initiatives and policies that would improve women's participation in these areas are made.

This document was requested by the European Parliament's Committee on Citizens' Rights and Constitutional Affairs.

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Manuscript completed in April 2020

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
CS	Computer Science
ERAC	European Research Area and Innovation Committee
GDP	Gross Domestic Product
ICT	Information and Communication Technology
IT	Information Technology
SWG	Standing Working Group
STEM	Science, Technology, Engineering, and Mathematics
SWOT	Strengths, Weaknesses, Opportunities, And Threats

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EXECUTIVE SUMMARY

Gender parity is vital to the prosperity of the EU, because it has been found to affect GDP, levels of employment, and productivity. STEM fields and the digital sector (e.g., digital technologies, CS, IT, ICT, AI, cybersecurity) are among the employment domains where gender bias prevails. Hence, addressing these inequalities is of high importance, especially when considered within the frame of the EU's principles and values.

This document has been prepared at the request of the FEMM Committee (Policy Department for Citizens' Rights and Constitutional Affairs, Directorate-General for Internal Policies). Major areas of concern for the Committee include the evidence of persisting biases and inequalities in STEM fields and the digital sector, in spite of the fact that these biases and inequalities were identified several decades ago and efforts have been made to address them over the years. Against this background, new policies and initiatives must be considered to eliminate the gender gap, which in turn will boost prosperity at all levels.

The document aims at providing an up-to-date literature review on the current status of women's representation in STEM fields and the digital sector. In so doing, the corresponding trajectories are examined, from the primary education level up to the labour market level, in an attempt to identify positive feedback loops and bottlenecks that prevent gender parity. Finally, suggestions for future research, initiatives and policies that would improve women's participation in these domains are made.

In primary education, STEM attitudes do not differ between girls and boys, while girls do not endorse gender stereotypes. Indeed, girls often outperform boys in grades and ICT literacy tasks. Given these differences in attitudes and performance, it is quite interesting that girls expect to be less successful than boys in STEM related careers and that fewer girls than boys are interested in a STEM career at the beginning of high school. Tools and methods with a beneficial impact on female STEM attitudes and performance are: (1) spatial tools, (2) role models, role playing, and mentoring for achieving gender balance, and (3) linking self-efficacy in STEM to being a "representative girl".

Initial interest at the start of high school and distancing from traditional gender roles favoured positive STEM attitudes. However, girls lag behind boys in math achievement, with adverse implications for their STEM attitudes. Another key finding was that girls tend to perform well on both math and verbal ability, compared to boys, who perform well in math only, which offers girls a broader range of possible options, and results in girls being less prone than boys to choose STEM. Despite the stereotypical treatment of female adolescents by males, including teachers and peers as well as parents, having a supportive male teacher who listens to and values students or having a supportive network of STEM peers enhanced female STEM attitudes. In these cases, it should be noted that teacher or parental support may backfire for female self-concept anytime it reminds females of the deficit in interest or ability that is the reason for requesting support in the first place. The time frame for consolidating STEM interest for students is confined to lower secondary education, within a period when girls are less likely than boys to maintain STEM interest or maintain positive self-concept of computer ability. Previous reform initiatives in Europe aiming to make the STEM domain more attractive to females failed to achieve their goal, either when they restricted the choices available to students, as in the German case, or when they increased the options offered to students, as in the Swedish case.

Although there were improved trends, female participation in STEM and CS throughout all levels of tertiary education still lags behind that of males. Female students in higher education display lower

perceptions of their own abilities, while they tend to attribute responsibility and blame to themselves, anytime they are not able to engage in activities to the same extent as their male colleagues. A core concern here is that the dominant, masculine cultures in higher education institutions are reproduced by means of bias intervening in search committees and hiring decisions. The gender productivity gap in highly cited journals, which disfavours females, increases with productivity, and may be better explained by gender discrimination than gender differences in abilities or choices. Percentages of undergraduate women in the USA reporting sexual harassment from their instructors are alarming and point to a thorough investigation in the European context as well. Evidence shows that female instructors, contact with advisors, or participation in study groups are not always beneficial for female persistence and STEM attitudes.

In terms of employment, encouraging trends have been documented for women employed as scientists and engineers, with a mean annual increase of 2.9% between 2013 and 2017, and in knowledge-intensive activities, where the proportion of women (around 44%) is much higher than that of men (around 29%). However, the percentage of women in ICT careers still remains below 2% of women's total share in the European labour market. Research has shown that women can be as motivated as male respondents to engage in STEM if not discouraged by gender bias. Gender diversity enhances female attitudes in teams and team performance, and it improves the potential for innovation for technological companies. Indeed, board gender diversity yielded higher firm performance, when there was a critical mass of women on the board. Despite all these beneficial effects, there are still gender gaps in upper-level positions and salaries, while current institutional arrangements to address family life do not fully compensate for all impacts experienced by women.

At the EU level, gender equality is expected to have a series of positive impacts on the GDP of the EU, the competitiveness and balance of trade of the EU economy, and job supply. Comparing between institutions established to close the gender gap in the USA and in Europe, the repertoire of institutions in the USA is richer and involves engaging women at the individual level of reference, mentoring, and gender equality in the workforce. In contrast to the grassroots origin of most initiatives in the USA, European institutions committed to promoting gender equality are more stakeholder-based and organized as networks of actors in a top-down fashion, lacking vertical connections to local contexts.

The gender gap concerning AI and cybersecurity is the largest among all digital technology domains. The average percentages of females in AI and cybersecurity, worldwide, are 12% and 20%, respectively. Both the AI and cybersecurity domains still carry gender stereotypes and biases. There are also personal and societal barriers that affect the selection of a career in these domains. Several efforts have been made to achieve gender parity, some of which have proven effective. However, these promising practices are rather short-range, since they have been applied with a very small sample and only in certain countries.

Our review revealed the priority of socio-cultural determinants of the gender gap over biological factors or factors measured at the individual level of reference. This implies that the decisions of individual women and men are always mediated by concrete socio-cultural contexts and cannot be examined in isolation. We exemplify how interventions for closing the gender gap may backfire, when they fail to account for domino effects with detrimental impacts on female self-efficacy and sense of belonging. Therefore, these interventions should not be delivered as “staged” events, but they should be designed for real-world contexts.

We suggest the establishment of a European Platform for Gender Equality (macro-level), funded and supported by the European Commission to coordinate stakeholder collaboration, for instance, in the development and implementation of a toolkit for gender equality as well as in the collection and analysis of cohort data anchored in real-world contexts. Targeted interventions under the umbrella of the Platform need to address positive feedback loops and "bottlenecks" identified, and they also need to guide the future research directions we have recommended (meso-level). At the micro-level, we have proposed certain avenues for problematizing reference material, pedagogical approaches, and peer interaction in schools. Finally, we have drafted a concrete example concentrating on focus schools, to exemplify how stakeholders may coordinate their joint action under the proposed Platform by means of participatory scenario development.

1. GENERAL INFORMATION

1.1. Introduction

This document has been prepared at the request of the FEMM Committee of the Policy Department for Citizens' Rights and Constitutional Affairs of the Directorate-General for Internal Policies.

Major areas of concern for the Committee include the evidence of persisting biases and inequalities in STEM (Science, Technology, Engineering, Mathematics) fields and the digital sector (e.g., digital technologies, computer science, Information Technology, Information and Communication Technology, Artificial Intelligence, cybersecurity), in spite of the fact that these biases and inequalities were identified several decades ago and efforts have been made to address them over the years. However, the gender gap still persists. Against this background, new policies and initiatives must be considered, at the micro-, meso- and macro-levels, to eliminate these gender gaps, which in turn will boost prosperity at all levels across the European Union.

A genderless sufficient labour supply from the STEM (Science, Technology, Engineering, Mathematics) fields and the digital sector (e.g., digital technologies, computer science, Information Technology, Information and Communication Technology, Artificial Intelligence, cybersecurity) is an essential condition for implementing the European Agendas for Education, Research and Innovation, and Growth and Job. In other words, gender parity is vital to the prosperity of the European Union, since it has been found to affect, among other things, the GDP, levels of employment, and productivity[1].

Below we provide the findings from a systematic literature review of the STEM fields and the digital sector in an attempt to present the gender-related biases and inequalities that still create obstacles and/or bottlenecks in these fields and restrict gender parity from happening. In so doing, the corresponding trajectories were examined and are presented, from the primary education level up to the labour market level. The idea was to study these trajectories and identify the critical points at which females are negatively impacted. This report was structured and organized in accordance with these trajectories. Specifically, the report starts with the presentation of the findings for the various education levels (i.e., primary education, secondary education and higher education), followed by the findings concerning employment and the presentation of examples of gender bias and inequalities from the digital employment sector. For the latter, the domains of Artificial Intelligence and cybersecurity (i.e., Computer Science domains) were selected, since they are among the domains where the percentage of female employees is among the lowest across the STEM fields and the digital sector, and despite the fact that the demand for labour in these two domains has increased drastically over the years. After that, the main findings are discussed, and finally, policy recommendations are made.

1.2. Methods

For the purposes of this report a systematic literature review was conducted. Both scientific and grey literature were used.

To screen and select scientific literature for the present study, we used SCOPUS and run a search with the keywords "gender" and "STEM" or "ICT" or "information and communication" or "computer science". We confined the search to scientific articles or reviews in international peer-reviewed journals published in English between 2010 and 2020 (search run on 25 February 2020). This search yielded 333

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[1] European Institute for Gender Equality (2020). Economic Benefits of gender equality in the European Union.

manuscripts. We excluded all papers referring to "stem-cells" (genetics/molecular biology) or "stem" (phytology/botany/plant anatomy/plant physiology). In addition, we excluded all papers published in non-citation-index journals. In addition, we used grey literature in our review, which was screened and selected by the European Parliament's Committee on Citizens' Rights and Constitutional Affairs. The final list is comprised of 185 references, which are presented in Reference list 1.

To present a synopsis of our main findings for primary education, secondary education, higher education, and employment, we used a SWOT (Strengths, Weaknesses, Opportunities, and Threats) template. The rows of the template depict in-group aspects (among females themselves), which were found to either promote or hinder gender equality (Strengths and Weaknesses, respectively), as well as inter-group aspects (interaction of females with students, parents, or peers; institutional arrangements; initiatives by policy-makers or employees), which, again, either promoted or hindered gender equality (Opportunities and Threats, respectively). The SWOT templates are given as Annexes (see Annexes I-IV).

We should highlight that these SWOT templates may be readily used by policy-makers, since they illustrate the aspects to build upon in order to foster gender equality (i.e., Strengths and Opportunities), as well as the aspects that need to be confronted for the same purpose (Weaknesses and Threats). An analogous planning and decision-making heuristic is the procedure for participatory scenario development, which we present in detail in Section 9. Ideally, the SWOT templates can be used in combination, first by identifying Strengths, Weaknesses, Opportunities, and Threats, in selected topical areas, and then allocating available or needed resources to foreseeable or desirable futures so that stakeholders may effectively steer their concerted action to address these priorities by participatory scenario development.

Given the scarcity of studies in the AI, cybersecurity and grants (i.e., funding in academia) domains concerning gender bias and how they contribute to gender inequalities that were published in citation-index journals in the last decade, we decided to extend the period of research from 2005 to 2020 and to use the Google Scholar search engine in addition to SCOPUS. Google Scholar allowed a search that included both citation-index and non-citation-index journals. The idea was to expand our literature review as much as possible in the domains of cybersecurity, artificial intelligence and grants for funding research in STEM fields and the digital sector. The keywords used this time included the terms "gender" and "artificial intelligence" or “cybersecurity” or “grants” or “funding”. This search enabled us to increase the number of papers reviewed in all of these domains. After reading the abstract of the identified papers, we deemed which were appropriate/relevant for this report. At a second stage, in order to avoid any sort of bias, we selected studies/papers whose findings were triangulated with the findings of other papers either inside or outside the citation-index article list, while checking/evaluating the quality of the methods followed in each one of these studies. For the latter we used a scoring rubric table, which among other things required checks on the sample size, the sampling process, the instruments used, and issues of validity and reliability. Any article that did not meet all criteria was disregarded. The final list for this second literature review process is presented in Reference list 2 (67 references, overall).

Finally, for elaborating on the main discussion points of our review and the policy recommendations, we used a series of additional references presented in Reference list 3 (9 references).

2. SUMMARY OF KEY FINDINGS

Primary education

1. Attitudes toward STEM do not differ between girls and boys, while girls do not seem to have yet endorsed dominant gender stereotypes. Indeed, girls often outperform boys in grades and actual performance in ICT literacy tasks.
2. Given these differences in attitudes and performance, it is quite interesting that girls expect to be less successful than boys in STEM related careers and that fewer girls than boys are interested in a STEM career at the beginning of high school.
3. Tools and methods with a beneficial impact on female STEM attitudes and performance are: (1) spatial tools, (2) role models, role playing, and mentoring for achieving gender balance, (3) linking self-efficacy in STEM with being a "representative girl".

Secondary education

1. Initial interest at the start of high school and distancing from traditional gender roles were found to favor STEM attitudes.
2. However, girls have been reported to lag behind boys in math achievement, with adverse implications on female STEM attitudes.
3. On average, girls tend to perform well in both math and verbal ability, compared to boys, who perform well in math only, which offers females a broader range of possible options, and which results in girls being less prone than boys to make a STEM choice.
4. Despite the stereotypical treatment of female adolescents by males, including teachers and peers as well as parents, having a supportive male teacher who listens to and values student or having supportive network of STEM peers had a positive effect on female STEM attitudes.
5. In these cases, it should be noted that teacher or parental support may backfire for female self-concept anytime it reminds females of the deficit in interest or ability that was the reason for requesting support in the first place.
6. The time frame for consolidating STEM interest for students is confined to lower secondary education, within a period when girls are less likely than boys to maintain STEM interest or maintain a positive self-concept of computer ability.
7. Previous reform initiatives in Europe that aimed to make the STEM domain more attractive to females failed to achieve their goal, either when they restricted the choices available to students, as in the German case, or when they increased the options offered to students, as in the Swedish case.

Higher education

1. Although there have been some recent improvement in some trends for female representation, female participation in STEM and CS throughout all levels of tertiary education still lags substantially behind that of males.
2. Female students in higher education in Europe and elsewhere perceive their own abilities as lower, while they tend to attribute responsibility and blame to themselves, anytime they are not able to engage in activities to the same extent as their male colleagues.
3. A core area of concern is whether the dominant, masculine cultures in higher education institutions are reproduced by means of bias intervening in search committees and hiring decisions. Percentages of undergraduate women in the USA reporting sexual harassment from their instructors were alarming and necessitate a thorough investigation in the European context as well.

Higher education

4. Female persistence in STEM majors dropped when the introductory STEM course was taught by a female instructor, which may be attributed to female students receiving lower grades in courses taught by female instructors, leading to relatively decreased persistence.
5. Increased contact with advisors and participation in study groups was negatively linked to timely degree completion in STEM for female students, which may be attributed to the fact that support-seeking may backfire for STEM self-concept.
6. Available evidence shows that the gender productivity gap in highly-cited journals, which disfavours females, increases with productivity, and may be better explained by gender discrimination than gender differences in abilities or choices.

Employment

1. Encouraging trends have been documented for women employed as scientists and engineers, with a mean annual increase of 2.9% between 2013 and 2017, and in knowledge-intensive activities, where the proportion of women (around 44%) is much higher than that of men (around 29%).
2. However, the percentage of women in ICT careers still remains relatively low, and it is currently below 2% of women's total share in the European labor market.
3. Research showed that women can be as motivated as male respondents to engage in STEM if not discouraged by gender bias.
4. Gender diversity enhances female attitudes in teams and team performance, and it improves the potential for innovation for technological companies.
5. Indeed, board gender diversity yielded higher firm performance when there was a critical mass of women on the board.
6. Despite all these beneficial effects and expectations, there are considerable gender gaps in upper-level positions and salaries, while current institutional arrangements to address family life do not seem to fully compensate for all impacts experienced by women.
7. Quite interestingly, gender differences and unintended discrimination were detected in the delivery of social media ads for STEM careers.
8. At the EU level, gender equality is expected to have a series of positive impacts on the GDP of the EU, the competitiveness and balance of trade of the EU economy, and job supply.
9. Comparing between institutions established to close the gender gap in the USA and in Europe, the repertoire of institutions in the USA is richer and involves engaging women at the individual level of reference, mentoring, and gender equality in the workforce.
10. In contrast to the grassroots origin of most initiatives in the USA, European institutions committed to promoting gender equality are more stakeholder-based and organized as networks of actors in a top-down fashion, lacking vertical connections to local contexts.

Artificial Intelligence – cybersecurity

1. The gender gap between females and males continues to exist across all digital technology domains, with Artificial Intelligence and cybersecurity being among the domains with the largest gaps. The average percentages of females in AI and cybersecurity, worldwide, are 12% and 20%, respectively.
2. Both the Artificial Intelligence and cybersecurity domains still carry stereotypes and underlying gender biases. There are also personal and societal barriers that affect the selection of a career in these domains.
3. Several efforts have been made to achieve gender parity in the digital sector, including Artificial Intelligence and cybersecurity, some of which have proven effective. However, these promising practices are of short-range, since they have been applied with a very small sample and only in certain countries. Further research is needed to examine their effectiveness in different countries and contexts.

3. PRIMARY EDUCATION[2]

3.1. Inconsistency between girls' attitudes and ability and their career beliefs

Girls do not differ from boys in pre-school and primary education in terms of their attitudes toward STEM[3,4] and they seem to outperform boys in terms of ability, including STEM grades[5] and performance on ICT literacy tasks[6]. Indeed, girls in the 5th and 6th grades have been reported to show benefits in STEM school achievement when engaging at home in technology-based activities such as using online dictionaries or encyclopaedias and communicating through digital applications[7]. These findings are corroborated by empirical research and meta-analyses of studies with large sample sizes and coverage in Europe and elsewhere. Yet, career beliefs of girls with regard to STEM do not align with their attitudes and ability[8,9]. Indeed, this inconsistency between girls' STEM attitudes and grades, on the one hand, and their STEM career beliefs, on the other, marks the transition from primary to secondary school, which seems to be crucial for consolidating the mindset of female students with regard to field-specific ability beliefs[10]. Here we encounter a major "bottleneck effect"[11], which may set the scene for any future reduction in female enrolment in STEM subjects and degrees, and which needs to be thoroughly explored by means of qualitative and mixed methods research.

3.2. Opportunities for initiating and sustaining girls' interest

There are several options available for girls themselves or for pre-school and primary school teachers when designing educational interventions, that have been found to augment STEM interest, such as spatial tools and role playing in early childhood, as well as role models in the primary school. Concerning spatial tools, there are strong indications that their use at pre-school age has a long-term effect on STEM enrolment behaviour in adulthood[12]. Such research has been largely confined to retrospective inquiry due to the difficulty of any alternative research arrangement. However, this may miss important dimensions and determinants of student decision-making and behaviour, not to mention the context within which student behaviour is deployed. Therefore, a cohort study would be

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[2] The key findings reported in this chapter are presented in Annex I, in the form of a SWOT template.

[3] McGuire et al. (2020), p. 6; the study involved 997 respondents from early childhood to adolescence in informal learning sites in the USA, including 407 respondents in early childhood aged between 5 and 8 years, with a mean age of 6.61 years.

[4] Zhou et al. (2019), p. 475; the study involved 877 Chinese primary school students from grade 1 to grade 6, in Guangdong, a central province in southern China.

[5] O'Dea et al. (2018), p. 3; this manuscript reported on a meta-analysis of 227 studies covering over 1.6 million students from grade 1 and above.

[6] Siddiq & Scherer (2019), p. 214; this manuscript reported on a meta-analysis of 23 studies in Europe and elsewhere.

[7] Burusic et al. (2019), p. 12-13, 15-16; the study involved 1205 students in the fifth and sixth grades in 16 primary schools in Croatia.

[8] Sadler et al. (2012), p. 424; the study involved 6860 high school students in the USA.

[9] Selimbegović et al. (2019), p. 1622; the study involved 880 Croatian primary school pupils with a mean age of 11.82 years.

[10] Wang & Degol (2017), p. 9.

[11] A "bottleneck effect" appears when a sharp decrease in a reference population is accompanied by an analogous variety decrease within this same population.

[12] Moè et al. (2018), p. 112; the study involved 176 Italian and German students in their first year of either a STEM or non-STEM degree.

warranted, to bridge transition periods between educational levels and explore effects of instructional practices on female student achievement and attitudes.

Moreover, role playing in pre-school can be designed and scaffolded so that professional and family roles are balanced for girls and exchanged between girls and boys[13]. Pedagogical design in role playing can influence social norms with regard to gender identity and behaviour, while it should aim to broaden the range of gender behaviours and roles deemed eligible by female students. For the primary school, role models of female figures have been suggested as a tool for involvement in STEM and inspiration for a STEM career[14]. A major issue here for educational systems, overall, is that both role playing and role models need to align with female gender identity and identification[15]. To be beneficial for countervailing gender disparities, female self-efficacy in STEM needs to become an integral part of female identity in preschool and primary school, namely, part of being a "representative girl". If this assumption is not met, role playing and role models may backfire and just perpetuate already existing gender stereotypes. Institutional support for pedagogical and instructional design for role playing and role models should be problematized in much more depth and detail, in this regard.

3.3. Barriers presented by social and academic environments

Differences between girls and boys in trusting gendered figures are already traceable at preschool age, as has been exemplified by recent research, with noticeable implications for STEM instruction. For example, pre-school girls and boys with similar STEM interest differed in trusting gendered animated media characters acting in STEM-related stories (video clips), with girls trusting female and male characters alike, and boys trusting male characters more[16]. It could also be that the same attitude is projected by males onto peer females or onto female teachers, which complicates the picture much more, given that female teachers prevail in preschool and primary school. A research question in this regard is whether trust of gendered animated or real characters is related to their acting, alone, within a narrative condition, and is context-bound, whether it is linked to the scientific message these characters convey, or whether it is linked to authority and other stereotypical indicators of social status. Future research should expand on this theme to investigate whether these hypothesized projections are substantiated.

Recent research has also showcased the failure of specific types of educational material to influence girls' interest in STEM at the primary school level, for instance, project-based learning educational interventions building on physical science[17]. Taken together, these findings imply that social and academic environments may present crucial barriers for girls in sustaining their STEM interest, and this may be exacerbated in the case of synergies. For instance, female students, already not interested in the educational material they still need to work with, may be further marginalized and discouraged in peer interactions and collaborative work by being trusted less than their male peers. Such a synergistic effect may further initiate a positive feedback loop locking female students into an unfavourable, inferior position as compared to male students. Again, more research is needed to untangle all these complex interactions between parameters, which are decisive for girls' interest in STEM.

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[13] Savinskaya (2017), p. 210-211, 2014.

[14] Barabino et al. (2020); p. 280.

[15] Selimbegović et al. (2019); p. 1624.

[16] Schlesinger & Richert (2017), p. 21; the study involved 48 children in Southern California aged from 3 to 6 years with mean age of 5.35 years.

[17] Zhou et al. (2019), p. 476.

4. SECONDARY EDUCATION[18]

4.1. Achievement and attitudes

Research findings with regard to achievement were mixed, with several reports presenting girls as having achievement equal to or better than boys in STEM[19], science and mathematics[20,21], and ICT[22], and other reports, which primarily concentrated on math achievement, depicting a trend for relatively lower performance by girls[23,24]. This trend for math achievement had adverse implications for female choice of STEM subjects[25] and intention to pursue a STEM career[26]. Indeed, there were numerous reports showing that girls lag behind boys in terms of self-concept in math[27] and self-efficacy in science[28], as well as interest in STEM majors[29] and in pursuing STEM careers[30,31]. An analogous disadvantage for girls in attitudes has been documented in the case of computer ability and interest in ICT-related studies[32], as well as occupational expectations for computing and engineering[33].

A quite interesting finding was that female students tend to perform well in both math and verbal ability, whereas male students have higher scores in math than verbal ability[34]. Although this should not count as a disadvantage for females, it results in females having a broader range of possible options than males, and results in a major gender divide, with boys being much more prone than girls to make a STEM choice[35]. Such a gender difference may explain why girls scoring highest in math ability do not opt more often for CS, engineering, and physics[36]. In addition, it implies that interventions that concentrate on both math and verbal skills may be more effective to sustain female interest in STEM[37].

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[18] The key findings reported in this chapter are presented in Annex II, in the form of a SWOT template.

[19] Jungert et al. (2019), p. 493; the study involved 1597 high school and junior college students from Canada and Sweden.

[20] Friedman-Sokuler & Justman (2020), p. 5; the study involved a data set of 166269 Israeli students enrolled in 8th grade in Arabic-language and non-religious Hebrew-language state schools during the school years 2002 and 2003, and matriculation records of all students in both cohorts enrolled in the twelfth grade in 2005/6 and 2006/7.

[21] Niepel et al. (2019), p. 1124; this study used PISA 2012 data sets comprising 120270 15-year-olds from 23 countries.

[22] Ansong et al. (2020), p. 11; the study involved 135 junior high school students from three schools in Greater Accra, one of the 10 administrative regions of Ghana.

[23] Meggiolaro (2018), p. 15; the study used PISA 2012 data for Italy with 28111 15-year-old students.

[24] Cheryan et al. (2017), p. 20.

[25] Delaney & Devereux (2019); p. 223-224; this review used data from the Central Admissions Office in Ireland for all students who did their Leaving Certificate, the terminal exam for high school, and then applied for degree courses in an Irish higher education institution in the years 2015 to 2017.

[26] Wang et al. (2015), p.6; the study used data from the 1987 Longitudinal Study of American Youth with two cohorts, namely, 3116 students in the 7th grade with mean age of 12 years and another 2829 10th graders with a mean age of 15 years.

[27] Niepel et al. (2019), p. 1124.

[28] English et al. (2011), p. 396; the study involved 122 students in middle school in Australia.

[29] Tellhed et al. (2017), p. 90-92; the study involved 1327 senior high school students with a mean age of 18.89 years.

[30] Ergün (2019), p. 102; the study involved 892 middle school students in Turkey.

[31] Turner et al. (2019), p. 145; the study involved 366 10th through 12th graders in the USA.

[32] Sáinz & Eccles (2012), p. 495-496; the study involved 424 secondary school students in Spain sampled twice within a two-year period, with mean age equal to 15 and 16 years in the first and second rounds of data collection, respectively.

[33] Han (2016), p.180; the study used PISA 2006 data with 360264 15-year-olds in 49 countries.

[34] Wang & Degol (2017), p. 3-4.

[35] Wang & Degol (2017), p. 6.

[36] Cheryan et al. (2017), p. 20.

[37] See, for example, Wang & Degol (2017), p. 15.

There is encouraging evidence that female adolescents do not endorse gender stereotypes for STEM, for example, that boys should be better in STEM than girls[38]. In addition, longitudinal research revealed that family expectations of female adolescents were not found to influence employment transitions for females, for instance, females willing to defer marriage or limit their fertility (childbearing) were no more likely to enter STEM occupations than females wishing to marry at an earlier age or have a relatively increased number of children[39]. Nevertheless, it seems that distancing from traditional gender roles at adolescence favours female STEM achievement, interest and career planning[40], as well as later employment in STEM fields[41]. All these results of recent research show that girls can be successful during secondary school in maintaining a discrete autonomy from traditional/conventional stereotypical beliefs, without having to limit their family expectations, and without being penalized for their choices in their STEM-related occupational trajectories.

4.2. Time window for choice of subjects and differential preferences of females and males

Recent research in Ireland has attributed most of the explained STEM gender gap in student preference rankings for college applications to subject choices and grades in secondary school, which can be traced back to two years before the college major choice[42]. This finding is corroborated with analogous indications for choice of STEM subjects[43], which implies that the time frame for consolidating STEM interest for students is smaller than all the years they will spend in secondary education, confining the time window for any intervention to address the gender gap, in terms of choice of STEM subjects, to lower secondary education[44,45].

Another crucial highlight from recent research, in this regard, was that females were less likely than males to maintain or develop STEM interest[46] or to maintain a positive self-concept of computer ability[47]. These latter trends indicate that females cannot find or sustain the motivation to take up or continue their trajectories in STEM subjects during the secondary school period. As a result of inflows and outflows from the STEM field in the USA, there are eventually 75% male and 25% female students interested in STEM careers at the end of high school [48]. Taken together, the empirical evidence seems to underline that interventions to close the gender gap in STEM need to be employed within a period of decreasing STEM interest for females.

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[38] McGuire et al. (2020); p. 6.

[39] Sassler, Glass, et al. (2017), p. 201; the study involved data from the 1979 National Longitudinal Surveys of Youth cohort in the USA, namely, 1258 women and 1115 men who completed a bachelor's degree, with 163 women and 353 men having completed a degree in a STEM field.

[40] Yu & Jen (2019), p. 11; the study involved 473 girls in the 10th grade from eight high schools across Taiwan, including 244 girls talented in math/science and another 249 girls gifted in language/social science.

[41] Dicke et al. (2019), p. 8; the study used data from the longitudinal Michigan Study of Adolescent and Adult Life Transitions with 2,474 participants over a time span of 30 years, from age 11 to 42.

[42] Delaney & Devereux (2019), p. 220, 222.

[43] You (2013), p. 81; data used were from the Education Longitudinal Study, with 12160 10th graders surveyed in 2002 and 10599 students who were enrolled in postsecondary education surveyed in 2006.

[44] Cheryan et al. (2017), p. 21.

[45] Wang & Degol (2017), p. 6, 12-13.

[46] Saw et al. (2018), p. 528; the study used data from the High School Longitudinal Study of 2009, with 20242 9th graders in fall 2009 in the USA.

[47] Sáinz & Eccles (2012), p. 495.

[48] Sadler et al. (2012); p. 419.

An additional weakness with regard to the choice of STEM subjects by females and the overall aim to close the gender gap is that girls show a particular interest in biology[49,50], which presents a weaker relation with subsequent choice of a STEM degree as compared to physics or engineering[51]. In the Irish case, which was introduced in the first paragraph of this section, 40% of secondary school males choose a STEM course as their first preference, while the relevant percentage for girls drops to 19%, with the difference driven mainly by choices in engineering/technology. Since girls and boys are more or less equally likely to choose the rest of the courses offered, there have been several calls to focus any interventions for addressing the gender gap in STEM on engineering/technology[52].

4.3. Initial interest

A key factor that predicted STEM career interest at the end of high school was initial interest at the start of high school, regardless of gender. Indeed, the odds of maintaining STEM interest at the end of high school may be nine times as high for secondary school students who declared initial interest as compared to those who did not[53]. In this case, initial interest in physics or engineering is a strength for girls, since it has been reported that girls with initial interest in these fields have an increased probability of persistence to the end of high school as compared to girls initially interested in other STEM fields[54]. These points about initial interest in STEM at the start of high school redirect us back to the point underlined in the previous section, namely, that a time window that is most crucial for closing the gap in STEM occurs in lower secondary education.

There are two similar findings that underline a type of initial interest in STEM for female adolescents. First, intention to work in a STEM field expressed by women as adolescents increases the odds of entering into STEM occupations after college completion compared to respondents who did not express such an expectation[55]. Second, the variation in the percentages of girls expecting a major in STEM as high school seniors in the USA (slightly more than 10%), claiming an initial college major in STEM (about 11%), and attaining a bachelor's degree in STEM (about 8%) was considerably less than that of males (about 30%, 25%, and less than 15%, respectively), meaning that women were more persistent than men and that they were less likely to "leak out of the pipeline" than men[56]. In relation to the trend of decreasing STEM interest, which was presented as the norm for females in the former section, it seems that a more concrete and determined form of interest (e.g., intention to work in a STEM field; expecting a major in a STEM field) may prove instrumental for addressing the gender gap in STEM. All the same, future research needs to explore whether this will be also validated for European contexts, since the two last findings were confined to the USA.

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[49] Riegle-Crumb & King (2010), p. 658.

[50] Mellén & Angervall (2020), p. 12; the study used data from the Gothenburg Longitudinal Database in Sweden, including four birth cohorts with youths born in 1978, 1982, 1988, and 1992, and having registered as Swedish citizens at the age of 16.

[51] Delaney & Devereux (2019), p. 225.

[52] Sadler et al. (2012), p. 419.

[53] Sadler et al. (2012), p. 421.

[54] Sadler et al. (2012), p. 423.

[55] Sassler, Glass, et al. (2017), p. 201.

[56] Ma (2011), p. 1179; the study involved data from the National Education Longitudinal Studies: 1988–2000, with 9370 students.

4.4. Social interaction

4.4.1. Student-teacher interaction

A main issue in social interaction is the stereotypical treatment of females by males, including teachers and peers[57] as well as parents[58], which has a marked negative effect on female's self-reported STEM attitudinal dimensions focusing on oneself, such as self-assessment[59]. An alarming finding was that middle school girls reported significantly lower mean value than boys with regard to teacher support in scaffolding STEM learning activities[60]. Although this finding may reflect perceived and not actual behaviour of teachers, it nevertheless indicates student-teacher interaction as a point of primary concern.

Apart from readily recognizable and desirable effects on gender stereotypical behaviour of males, when having a female teacher[61], or on females, when presented with female STEM career professionals as role models[62], there are additional opportunities to counter stereotypes without necessitating the presence of a female teacher or role model. Having a male teacher who listened to and valued student ideas decreased the odds of believing than men were better than women in math or science[63]. It is quite interesting that this effect was stronger for male teachers than for female teachers with the same behavioural characteristics (listening to and valuing student ideas)[64]. It has been also reported that role models who do not fit current masculine stereotypes of CS and are relatable to women are able to increase women's interest even if these role models are male[65]. Altogether, these effects underline the importance of teacher attitudes and instructional strategies.

4.4.2. Student-student interaction

Social interaction with peers also has a substantial role in either fostering or weakening STEM interest for female adolescents. For example, having a supportive network of STEM peers has been reported to attenuate the effect of gender bias experienced by high school female students on their STEM self-concept (i.e., if they felt that they were treated unfairly due to their gender)[66]. It seems that such a supportive STEM network can cultivate positive interactions among STEM peers and enhance the sense of belongingness of females in STEM, and through that sense, temper any self-doubt originating from other negative social interactions.

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[57] Hand et al. (2017), p. 941; the study involved 44 teachers and 121 students in a high school in the USA.

[58] Robnett (2016), p. 71; the study involved 108 girls at two high schools in the USA interested in pursuing a STEM career, with a mean age of 16.57 years.

[59] Liu (2018), p. 537; the study involved 17311 students in 112 schools of 28 counties in mainland China who completed the seventh or ninth grade in the 2013–14 academic year.

[60] English et al. (2011), p. 393.

[61] Riegle-Crumb et al. (2017), p. 502.

[62] Ansong et al. (2020), p. 14.

[63] Sansone (2019), p. 138; the study used data from the U.S. High School Longitudinal Study of 2009, with 21440 students in 9th grade from about 940 schools.

[64] An analogous result was reported for a convenience sample with an average age of 23,85 years (Krämer et al., 2016, p. 10; the study used 128 participants in the USA aged 18-34 years, with an average age of 23,85 years). In this case, virtual agents displaying rapport (i.e., simulating positive listening behaviours, for instance, nodding and smiling, in response to verbal and non-verbal behaviour of a human speaker) were found to enhance learners' performance and effort in mathematics; however, this effect was observed when participants interacted with agents of the opposite gender, meaning that females benefited more from a male virtual agent displaying rapport. These findings imply that matching the gender of an instructor may be less beneficial for females than configuring the behaviour of male instructors to display rapport.

[65] Cheryan et al. (2017), p. 14.

[66] Robnett (2016), p. 73.

An analogous case, where a positive effect of peer interaction on female STEM interest was observed, was when females were exposed to female classmates with a STEM-favourite subject[67]. In this case, female peers with explicit STEM preferences could protect other female peers from being discouraged from STEM subjects. This finding was crucial in exemplifying how peer exposure and interaction, as a social mechanism, may under certain circumstances counteract any penalties stemming from non-gender-conforming behaviour.

However, not all types of peer interaction may prove supportive for STEM interest.

Composition of peer groups (i.e., friendship groups, which fall within the scope of peer networks with a STEM orientation, or females with a pronounced STEM interest, as presented in the two former paragraphs) was found to negatively influence STEM interest among females, particularly when these groups presented increased participation by females[68]. Since both girls and boys are most likely to (1) like what their friends like and (2) have friends of the same sex, peer interaction operates to orient girls and boys to diverging trajectories[69]. Boys, with higher odds for relatively increased initial STEM interest, are likely to be further influenced in the same direction by their male peers; for girls, on the other hand, who have on average a lower initial interest in STEM, interaction with other girls is likely to catalyse their STEM interest negatively.

These findings may indicate an indirect, implicit mediation by social belongingness (i.e., believing oneself to fit better in majors dominated by peers of the same gender) of STEM interest[70], which needs to be explored in more detail. Another implication we need to note here is the existence of a positive feedback loop (where the outcome of an event or process amplifies the effect of this same event or process), which operates to create a bottleneck effect in secondary education, resulting in decreasing female numbers and overall gender diversity in STEM[71]. Namely, having fewer female students interested in STEM careers leads to females being deprived of social belongingness in STEM, which further holds back female STEM interest. Indeed, on a broader scale, it was found that females' self-concept in mathematics (perception of one's own mathematical ability) was higher in societies with higher gender diversity in STEM positions[72].

Overall, the results of recent research on social interaction reveal the significance and complexity of all potential influences, which may be exerted by teachers and peers of the same or different gender, on female STEM interest and attitudes. Given the fact that much of this interaction may be channelled through the pedagogical scenarios chosen by the teachers themselves, pedagogical and instructional design needs to take these considerations into account. To this end, learning goals and arrangements that are compatible with STEM education, and that may facilitate peer communication and interaction, should be adequately planned and delivered to promote the beneficial features of social interaction on female STEM attitudes, and at the same time, target its adverse impacts. For instance, methods that augment the desirable effects of peer communication and interaction, such as the development of 21st century skills, the jigsaw approach, and peer assessment, need to be fully exploited.

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[67] Raabe et al. (2019), p. 118, 119.

[68] Robnett & Leaper (2013), p. 661; the study involved 468 high-school students in northern California, USA.

[69] Raabe et al. (2019), p. 119; the study used the Swedish subset of the Children of Immigrants Longitudinal Survey in Four European Countries data set, with 5025 students from 251 classes in 129 schools aged 14 or 15 years.

[70] Tellhed et al. (2017), p. 90-92.

[71] see in this regard Ganley et al. (2018), p. 476-477; the study used data from the Education Longitudinal Study of 2002 with 4850 10th graders and two follow ups, one when these students were in the 13th grade and the second one two years later.

[72] Niepel et al. (2019), p. 1125.

4.4.3. Student-parent interaction

Several research findings point to the stereotypical behaviour of parents in terms of the gender of their daughters when it comes to STEM and ICT studies or careers, in Europe and other contexts. Interestingly, both mothers and fathers were found to display various types of stereotypical behaviour. Parents in Spain, particularly mothers, who endorsed stereotypical beliefs about IT professionals as distanced from female characteristics, were less likely to encourage their children, particularly their daughters, to enrol in ICT studies[73]. In another research setting, parents of males in the USA were more likely to believe their child had higher mental manipulation and navigation abilities than parents of females, even after controlling for the actual ability of their children[74]. In the same context, child encouragement to pursue a STEM career was positively correlated with parents' perception of their child's higher ability, while students with such parents were more likely to report intention to choose a STEM major in college (proximal outcome) as well as intention to choose a STEM career (distal outcome).

4.4.4. Adverse effects of support provided by teachers and parents

A quite interesting study in Germany involved 296 female university students in STEM subjects with a proportion of females equal to or lower than 30%[75]. This study showed that female experiences in secondary school may have an impact on their STEM self-concept when reaching university. Among a series of effects outlined, two were counter-intuitive and deserve much attention in pedagogical/instructional practice and policy-making. Specifically, support provided to females by their teachers to facilitate STEM interest or by their parents to support their performance in STEM had an adverse influence on the self-concept of these same females when they reached university. The fact that teacher or parental support may backfire for female self-concept can probably be explained by a preceding lack of interest or ability, respectively, which is most probably indicated by the females' move to ask for and receive support in the first place[76]. These findings imply that support provided by teachers and parents to secondary school female students needs to be adequately configured and delivered so as not to prove detrimental for female STEM self-concept.

4.5. Socio-cultural aspects

Two important studies focusing on Israeli Hebrew- and Arabic-speaking females were illustrative of the heterogeneity and complexity of the effects exerted by socio-cultural aspects on female STEM choices. Girls in Arabic schools were more likely to choose mathematics, physics and CS in science electives than Arab boys at the end of high school, while the reverse was true in Hebrew-language schools[77]. Another study reiterated these findings for advanced physics and CS classes: In an Israeli Arabic speaking high school, the majority of students in these classes were females, in contrast to a Hebrew speaking state school, which displayed the typical gender gap in physics and CS[78]. However, these preferences were not further reflected in corresponding subject choices at the university level or in the labour market.

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[73] Sáinz et al. (2012), p. 245; the study involved 27 fathers and mothers of secondary school students in Spain and 22 teachers of these students, in focus groups.

[74] Muenks et al. (2019), p. 9-10; the study involved 117 students in public high schools in the USA with a mean age of 16.66 years, as well as one of their parents.

[75] Ertl et al. (2017).

[76] Ertl et al. (2017), p. 6, 8.

[77] Friedman-Sokuler & Justman (2020), p. 6.

[78] Pinson et al. (2020); the study compared between two different high school in Israel, a Hebrew speaking, and an Arabic speaking high school.

The question is, what were the motives behind female choices at the level of secondary education, if these did not materialise in subsequent studies of higher education institutes or occupational expectations?

One possible explanation, which needs to be supported by further research, and which may have important implications for racial/ethnic minorities in European countries, is that the choice of subject in secondary education is primarily driven by a culture-specific marriage-market incentive structure[79]. Given the fact that women in Arab societies need to take on much more responsibility for the socialization and education of their children as compared to women in Western contexts, their own education will be valued accordingly as an asset. This benefit, however, is only confined to family life and child raising. Although more research will be needed to substantiate such a hypothesis for heterogeneous racial/ethnic contexts in European societies, it will be nevertheless an important implication for STEM choice and career prospects, if proven valid.

4.6. Policy reforms focusing on secondary education

Policy reforms may have quite differential effects on girls and boys. For instance, a reform in the German state of Baden-Württemberg requiring all students to take advanced math courses, led to smaller gender differences in math achievement but larger gender differences in math self-concept (students' self-evaluation of their own ability in math). Interestingly, female math self-concept decreased significantly after the reform, although their math achievement increased. Female enrolment in STEM subjects at the university did not significantly change after the reform[80]. These findings suggest that intervening in choice of subjects (reducing choices for students) does not necessarily lead to increased gender equality in STEM fields.

A quite similar consideration was voiced for high schools in the USA, where gender differences in course participation increased with freedom to choose these courses, which was found to orient many girls out of STEM classes, for instance, engineering, physics, and CS[81]. Although it may seem at first glance that making the above courses mandatory would restore female participation, a major reservation is that this change alone may not be enough to sustain female interest in STEM, unless the dominant masculine culture in these fields is also counteracted[82]. And this reservation seems to be corroborated by the results of the German reform presented in the former paragraph.

Another top-down initiative to make the STEM domain more attractive to females, particularly technology, and to improve gender equality, was taken by the Swedish government in 1994. Schools were able to adjust curricula in upper secondary education to the needs of the local labour market, while students were able to make individual choices (the number of subjects to be chosen by students increased). However, the reform goal was not reached in this case either, since females followed more or less the same trajectories. The gender gap in STEM does not seem to be effectively addressed by just re-organizing educational programmes in a top-down fashion[83]. Indeed, neither restriction of student choices, as in the German case presented above, nor increase in options offered to students, as in the

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[79] Friedman-Sokuler & Justman (2020), p. 10.

[80] Hübner et al. (2017), p. 1003; data used were from the Transformation of the Secondary School System and Academic Careers, with students in the final year of upper secondary school in the German state of Baden-Württemberg, specifically, 4730 students surveyed in 2002, before a reform requiring all students to take advanced math courses, and 4715 students surveyed in 2006, after the reform.

[81] Cheryan et al. (2017), p. 14.

[82] Cheryan et al. (2017), p. 21.

[83] Mellén & Angervall (2020), p. 11.

Swedish case, was enough to accomplish the objectives of both reforms. The effect of broader socio-cultural factors, which will continue operating in parallel with any introduced reform, seems to be extremely important, especially in producing and reproducing the gendered character of STEM subjects.

5. HIGHER EDUCATION[84]

5.1. Choice of subjects

5.1.1. Female percentages lag behind male figures across all levels of tertiary education

Female participation in STEM throughout all levels of tertiary education still lags substantially behind that of males. Female graduates at the B.Sc. (32%) and M.Sc. levels (36%) are much fewer compared to relevant female figures for the entire field of tertiary education (23 percentage points lower), while female representation is slightly improved for doctoral graduates in STEM (39%; 9 percentage points lower than their share over all fields). An illustrative example of inequality in the STEM field, with further implications for the reproduction of academic positions in European universities, is reflected in the dramatically decreasing percentage of female academic staff as we move up the scale in academic positions in STEM: Females occupy 35% of grade C positions, 28% of grade B positions, and only 15% of grade A positions, and these percentages are considerably lower than the respective figures for all fields taken together[85].

5.1.2. The special case of Computer Science

Overall, CS is a field having female underrepresentation throughout the last four decades[86,87], which is reflected in quite salient gender stereotypes for the field, favouring males[88], with marked adverse effects on female self-efficacy and interest[89]. Even undergraduate female students in CS believe that CS is a male domain, with these same students being characterized by high anxiety, lack of confidence, and underachievement[90]. Given the above background conditions, it is no surprise that gender differences were found to be mediated by sense of belonging among females in higher education learning environments. Indeed, only by replacing objects stereotypically associated with CS, such as science fiction books, computer parts and books, Star Wars and Star Trek items, with objects not stereotypically associated with CS, such as water bottles, a coffee maker, art pictures, and nature pictures, was female enrolment intention and anticipated performance stimulated to reach the level of their male peers[91].

However, gender differences in CS may refer not only to the subject itself but also to the courses chosen within a CS curriculum, which in return affects the selection of specialization in CS (e.g., more males choose to specialize in Artificial Intelligence and cybersecurity; for details, see sections 7.1 and 7.2). In fact, it was found that female university students preferred courses focusing on theoretical CS and

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[84] The key findings reported in this chapter are presented in Annex III, in the form of a SWOT template.

[85] She Figures 2018 (2019), p. 115.

[86] Sax et al. (2017); the study analysed data from 8 million students in baccalaureate-granting institutions from 1971 to 2011, with a focus on 18830 CS majors and another 904307 majors in other fields.

[87] Wagner (2016); data used were from 129 universities in the United Kingdom in the period 2002-2013.

[88] Ehrlinger et al. (2018); the study involved 269 college students in the USA.

[89] Beyer (2014); the study involved 1319 first-year students at a public university in the USA, with a subsample of 76 students being asked about their classroom experiences and another subsample of 128 students asked to predict future course-taking and grades in CS.

[90] Stoilescu & McDougall (2011); the study focused on seven undergraduate courses in CS at a university in Ontario, with 16 student interviewees.

[91] Cheryan et al. (2011); the study involved non-CS majors at a university in the USA, with 59 participants in the first experiments, 62 in the second, and 34 female participants only, in the third experiment.

social and human aspects of CS, whereas males preferred courses concentrating on hardware and software engineering[92]. Other research has reported gender differences in student behaviour within the same CS source, with female students being not as involved as their male colleagues in computer programming and related activities[93]. Therefore, it has been underlined that the gendering of fields such as CS may be more complicated than the split between a stereotypical bipole distinguishing a male-technical pole from a female-social pole[94]. These conditions may lead higher education institutions to reconsider the education curriculum offered in CS so as to attract more female students, as indicated by incorporating art courses and several structured synthesis experiences alongside traditional CS courses[95].

5.1.3. Female preference for doctoral studies

Although the data presented above show lower female participation, there are several indications that female figures are gradually improving in some areas of higher education, overall, and in STEM, in particular. Numbers of female and male students in university-level education are comparable in most Member States, while the number of women opting for a doctoral degree is increasing faster than the number of men pursuing the same goal[96]. Indeed, women's share of doctoral graduates has recently shown an increasing trend in several STEM fields and in several countries. Natural sciences, mathematics and statistics were the fields with most women graduating at the doctoral level in 2016 at the EU-28 level, with 26.6% of all female doctoral graduates[97]. Although female doctoral graduates at the EU level were still underrepresented in 2016 in ICT (21%) and engineering (29%, including manufacturing and construction)[98], the ratio of women starting doctoral studies to those having graduated from master's level studies was equal to or larger than the same ratio for men in 17 countries for ICT, and in 20 countries for engineering[99]. Moreover, the ratio of people who graduated from doctoral level studies to those having started doctoral level studies in 2016 was higher for women than men in 8 countries for ICT and another 21 countries for natural sciences, mathematics and statistics[100].

5.2. Gender stereotypes and gender bias

5.2.1. Females tend to undervalue their own capacities

The gender stereotypes found in primary and secondary education also exist in higher education, and they seem to be endorsed predominantly by male STEM students[101], but not solely by males[102]. Female students in higher education in Europe and elsewhere displayed lower levels of perceived abilities. For instance, gender stereotypes held by female university students in Germany in STEM subjects with a

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[92] Berdousis & Kordaki (2019), p. 1281-1285; the study involved a quantitative analysis of 89 undergraduate students' performance in and preferences for graduate CS courses at a CS and technology university department in Greece.

[93] Stoilescu & Egodawatte (2010); the study involved interviews with 16 undergraduate students and 2 instructors at a CS department of a university in Ontario.

[94] Kim et al. (2018); the study involved in-depth interviews with Korean majors in CS.

[95] Bares et al. (2018); the study elaborates on the Computing in the Arts interdisciplinary Bachelor of Arts degree program.

[96] Eurostat (2019), p. 4.

[97] She Figures 2018 (2019), p. 25.

[98] She Figures 2018 (2019), p. 6.

[99] She Figures 2018 (2019), p. 33.

[100] She Figures 2018 (2019), p. 33.

[101] Moè et al. (2020); p. 9; the study involved 132 STEM and 124 non-STEM students at three European universities in Norway, the United Kingdom, and Italy.

[102] Farrell & McHugh (2020), p. 151; the study involved 70 STEM students enrolled in an Irish university.

proportion of females equal to or lower than 30% were negatively related to their STEM self-concept (their own self-assessment in STEM)[103]. A lower perception of their own competence regarding the expectation of future success was reported for female master's STEM students in Germany compared to their male colleagues[104].

In Australia, female underrepresentation coincided with lower social belonging and self-efficacy among female university students, with the later parameter being considered as the most prominent issue; indeed, lower self-efficacy for females was documented even for STEM disciplines considered more gender-balanced, such as biology[105]. Analogous findings were reported in the USA, where White women were still found to report lower STEM confidence than White men[106], lower STEM self-efficacy and lower STEM interest[107]. A reason provided for self-perceived lower science performance by female students was that they believed that being a woman was perceived to interfere with being a scientist[108]. It may be that females in STEM fields have to confront a disconnect between a female social identity, on the one hand, and the STEM socially-constructed identity, on the other[109]. Female students perceive themselves as academically weaker, although they may not differ from their male colleagues in actual academic performance[110].

Indeed, females may graduate at lower rates in STEM degrees compared to their male colleagues despite having higher grade point averages[111]. Females in Chinese colleges showed significantly lower achievement motivation than their male colleagues, which was linked with traditional gender role motives, and which was also highlighted as a major reason for dropping out of STEM fields[112].

Given these circumstances, it should be no surprise that females were less likely than males to persist in a STEM field after their first semester[113] and that females were more probable to outflow from STEM to non-STEM majors[114], with lower scores in self-concept for math/science being among the prominent characteristics of females leaving STEM majors for non-STEM majors[115].

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[103] Ertl et al. (2017), p. 6.

[104] Sobieraj & Krämer (2019), p. 14; the study involved 888 master's students in STEM or non-STEM subjects in higher education institutions in Germany.

[105] Fisher et al. (2020), p. 5, 8; this review covered 36 scientific papers concentrating on gender issues for university STEM students in Australia.

[106] Litzler et al. (2014), p. 826; the study used data from the 2008 online PACE study with 10366 undergraduate engineering students.

[107] Hardin & Longhurst (2015), p. 237; the study involved 184 students enrolled in an introductory chemistry course at a university in the USA surveyed twice within a semester.

[108] Settles et al. (2016), p. 496; the study involved 639 female undergraduate students at a public university in the USA.

[109] Piatek-Jimenez et al. (2018), p. 1449; the study involved 499 undergraduate students at two universities in the USA.

[110] MacPhee et al. (2013), p. 362; the study involved 175 students in STEM majors from underrepresented groups, including females, in the USA.

[111] Gayles & Ampaw (2014), p. 462; the study used data from the 1996/2001 cohort of Beginning Postsecondary Students longitudinal study with a selection of 1488 participants in the USA who provided responses in three waves, 1996, 1998, and 2001.

[112] Yang & Gao (2019), p. 12, 15; the study used data from the Third National Survey on the Social Status of Chinese Women, with 1142 undergraduate, 704 master's, and 349 PhD students from 12 disciplinary areas.

[113] Price (2010), p. 908, 909; data used were from the Ohio Board of Regents in the State of Ohio, USA, with over 155000 students, of whom 22.1% had an initial intention to pursue a STEM major.

[114] Ackerman et al. (2013b), p.39; the study involved 26693 students in their first year at the Georgia Institute of Technology from fall 1999 to fall 2009, including 30.1% female students.

[115] Ackerman et al. (2013a), pg.33; the study involved 589 first-time college students at Georgia Tech.

5.2.2. Responsibilisation and contradictory incentive structures for female academics and researchers

Leaving maternity aside, both female and male academics and researchers in working at European Universities did not consider their cultures and practices as gendered, meaning that they were not able to refer to any effect of their gender in their academic career; indeed, female respondents attributed responsibility and blame to themselves anytime they acknowledged that they were not able to engage in activities to the same extent as their male colleagues[116], which needs to be framed within a broader responsibilisation culture permeating academia. By "responsibilisation" we describe a process of assuming responsibility for one's own livelihood irrespective if there could be other barriers for one's success or determinants of one's failure, for example, institutional arrangements[117,118].

Although more research is needed to validate this finding, we should highlight the contradictory motives which may be at play for female academic careers. If responsibilisation is, indeed, necessary to be taken up as personal strategy for succeeding in academia and elsewhere, if it is taken to exemplify an individual's competence to overcome obstacles and resume one's autobiography without the need of external assistance and subsidies and if this strategy is explicitly or implicitly rewarded across several stages of one's career as a sign of one's ability and autonomy, then both males and females candidates should be able to deploy such a distinguishing feature. In this case, using gender as an excuse for staying behind or claiming any "privileged" or otherwise differential judgment may be regarded as a major weakness compared to other competitors. Indeed, this may be also the case if the same academic or occupational culture recognizes gender disparity at a general level of reference. Next to these assumptions, which have to be prioritized in the forthcoming research agenda, there is also the issue of solidarity among female academics and researchers, which may be jeopardized if a certain segment of the female population chooses the path of "responsibilisation" and another disregards or undervalues this same path.

5.2.3. The gender productivity gap

Available evidence shows that the gender productivity gap in highly-cited journals, which disfavours females, increases with productivity and may be better explained by gender discrimination than by gender differences in abilities or choices[119]. It was moreover found that female researchers with top productivity need more resources (e.g., knowledge, relationships, and investment of working hours) for arriving at the same result as their male colleagues[120]. With regard to CS, female scientists in academia were found to be less likely, on average, to follow the steps needed to secure career success, as quantified through citation impact and the h-index; among the steps identified were a relatively increased rate of collaboration with colleagues as well as long-lasting and repetitive collaborations[121]. The main trends reported above seem to apply to a variety of socio-cultural contexts across North

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[116] O' Hagan et al. (2019), p. 218; the sample involved 57 male and 49 female academics and researchers at four universities in Bulgaria, Denmark, Ireland, and Turkey.

[117] Dardot, P., & Laval, C. (2017). *The new way of the world: On neoliberal society* (trans. G. Elliott). London: Verso.

[118] Lemke, T. (2001). The birth of biopolitics: Michel Foucault's lecture at the Collège de France on neo-liberal governmentality. *Economy and Society*, *30*, 190–207. https://doi.org/10.1080/03085140120042271

[119] Aguinis et al. (2018), p. 1303; the study involved 59278 researchers with at least one publication in the most-cited journals including, among other, mathematics and genetics.

[120] Aguinis et al. (2018), p. 1301.

[121] Jadidi et al. (2018); the study analysed publication data referring to more than one million computer scientists over the last five decades.

America, Africa, and Asia[122,123]. In the EU-28, engineering and technology was the field with the lowest average ratio of female to male contributing authors on scientific articles during the period 2013-2017[124], while the same field presented the lowest value for the SGDRC indicator, depicting the percentage of research output in a country that has integrated a sex or gender dimension in research content[125], with just 0.15 % for the period 2013-2017[126].

5.3. Social interaction

5.3.1. The dominance and implications of cisgender male heterosexuality in higher education institutes

Previous research has shown how the hegemonic norm of cisgender male heterosexuality prevails in higher education environments in the USA[127]. This norm, in many cases manifested as hypermasculinity, has been observed to marginalize alternative forms of gender and sexuality discourses (lesbian, gay, bisexual, transgender, queer, intersex, and asexual), and objectify cisgender women; indeed, to be accepted in such intolerant environments, students with minoritized identities had to adopt and be identified as displaying attributes of the dominant hypermasculine culture[128]. Qualitative research has further revealed how dominant gender discourses necessitate an ongoing and multi-sided struggle by females in higher education institutions. For example, female university students in Computer Science had to come up with contradictory subject positions, interchanging invisibility with visibility, which added considerably to the complexity, heterogeneity, and contingency of experiences and narratives emerging anytime they attempted to push back on dominant gender discourses[129].

An issue of concern is whether the dominant, masculine cultures in higher education institutions is reproduced by means of bias intervening in search committees and hiring decisions. For instance, faculty in a physics department was found to favour hypothetical male candidates for a postdoctoral position, since they believed the male candidates were more competent and hireable than female candidates with identical CVs[130]. Interestingly enough, the above bias was not observed for faculty in biology departments, which may replicate a contrast between STEM fields found in student preferences. For instance, biology, selected as a STEM field more by female students, was not characterized by bias in hiring decisions by faculty as compared to physics, where gender bias seems to prevail both in terms of student preferences and hiring procedures. A promising sign that this type of gender difference can be overcome was provided by a study focusing on interventions designed to

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[122] Miller et al. (2012), p.44; the study involved face-to-face interviews with 540 scientists in Ghana, Kenya and Kerala, India.

[123] Mendoza-Denton et al. (2017), p. 4; the study involved data from the Berkeley Life in Science Survey conducted in 2013-2014 with 425 graduate students.

[124] She Figures 2018 (2019), p. 142.

[125] Calculated in the SCOPUS database by means of keywords sought among articles' keywords or in the articles' abstracts; see EC (2019), p. 152.

[126] She Figures 2018 (2019), p. 177.

[127] Simon et al. (2017), p. 311; the study involved a sample of 752 university students enrolled at a public university in the USA.

[128] Miller et al. (2020); p. 10; the study involved 51 undergraduate and 5 graduate students with minoritized identities of sexuality and/or gender in STEM from colleges and academic departments.

[129] Convertino (2019); the study involved interviews and focus groups with women students of colour enrolled in computer science at a university in the US.

[130] Eaton et al. (2020), p. 134-135; the study involved 251 faculty from biology departments and a physics department at eight public universities in the USA, who were asked to evaluate the CV of a hypothetical PhD graduate looking for a postdoctoral position.

minimize gender bias in academic search committees for faculty searches (short presentations on implicit bias; recruitment guidebook with tactics to offset bias; access provided to family advocates for a confidential discussion about work-life integration aspects). Specifically, these interventions were found to increase gender diversity among STEM faculty[131].

5.3.2. Student-instructor interaction

Recent research has reported a series of crucial and in some cases quite contradictory but still insightful findings with regard to student-instructor interactions and their impact on female STEM attitudes. A striking finding that needs to be underlined was that the majority of undergraduate women enrolled in biology courses at a public university in the USA (70.5%) acknowledged having experienced sexual harassment from their instructors in the previous year (including faculty, teaching assistants, or graduate students), which had a marked and adverse effect on their STEM value (importance, value and usefulness ascribed to STEM courses)[132]. Since sexual harassment from instructors is most probably taken to indicate a hostile academic climate, it may jeopardize female persistence in STEM courses, and in any case, reflects the failure of institutions to prevent this type of behaviour. Given the frequency of cases of sexual harassment and that it may be a reason on its own for women to leave academia[133], it needs to be treated much more drastically than is currently the norm. One idea is to handle sexual harassment in a similar way as scientific misconduct, by proceeding with analogous institutional arrangements and provisions for sanctions[134].

Engagement by female students and intention to seek instructor assistance once needed was found to increase for STEM courses taught by a female instructor[135]. However, there is also research pointing to an adverse effect of female instructors. Female students were less likely to persist in initial STEM majors when the introductory STEM course was taught by a female instructor[136]. This effect may be explained by the fact that female students tend to receive lower grades in courses taught by female instructors, and this leads to relatively decreased persistence. It goes without saying that more research is needed to substantiate these effects. Nevertheless, the available research shapes a complex picture, where no presumed social interaction or its effects should be considered self-evident, even gender solidarity among women. A related aspect linked recognition of gender issues with self-perception of one's responsibilities in the frame of teacher identity. Specifically, both male and female instructors did not consider intervening to support gender equality as part of their teacher identity, although they had acknowledged issues of gender inequality[137]. This means that acknowledgment of gender inequality does not necessarily translate into action taken by faculty to address it.

Another topic with contradictory findings was seeking support from an academic advisor, independent of her/his gender. On the one hand, there were clear indications that meeting with an academic advisor decreased the gender gap in earning a STEM degree, underlining the significance of academic

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[131] Smith et al. (2015), p. 1086; the study involved search committees for 23 STEM-faculty searches during one academic year at a university in the USA.

[132] Leaper & Starr (2019); p. 172, 177; the study involved 685 women undergraduates with a mean age of 19.67 years, enrolled in biology courses that are prerequisites for life science majors, at a public university in the USA.

[133] Greider et al. (2019), p. 692.

[134] Greider et al. (2019), p. 692-694.

[135] Solanki & Xu 2018, p. (829); the study involved data from the University of California, Irvine, with more than 8000 undergraduate university students enrolled in 23 STEM courses.

[136] Price (2010), p. 909; data used were from the Ohio Board of Regents in the State of Ohio, USA, with over 155000 students, of whom 22.1% had an initial intention to pursue a STEM major.

[137] Blair et al. (2017), page 31; the study involved 18 faculty teaching gateway introductory courses at three higher education institutions in the USA.

integration for female students[138]. On the other hand, meeting an advisor regularly and taking part in study groups was negatively linked to timely degree completion in STEM for female students[139]. This latter effect is reminiscent of the analogous influence documented already for the secondary education level, namely, that seeking support for STEM performance may backfire for STEM self-concept. To address these adverse effects of support on STEM self-concept, future research should examine whether pedagogical and instructional methods, such as peer assessment and inquiry-based learning, used to empower students and strengthen autonomy and self-regulation in learning, may also prove beneficial for STEM self-concept. This may be a way out of the above-mentioned conundrum, where pedagogical design and instruction are adequately configured and fine-tuned to promote student ability to effectively perform learning tasks. In an analogous manner, advisory services should also aim to empower students in a self-negating/fading sense, meaning that empowered students would no longer need to seek advice. These considerations also need to be taken into account while structuring and delivering mentoring programs for female students[140].

5.3.3. Student-student interaction

There are several outcomes of recent academic research that refer to peer interaction among students in higher education and that may have an influence on STEM and CS motivation and performance. For example, undergraduate female students perceived an increased probability of being isolated from peers when choosing CS, and that feeling referred to peers both within as well as outside CS[141]. Analogous impacts have been reported for collaborative work, specifically, the composition of peer groups and peer interaction in groups. With regard to group composition, it has been reported that team identification by female students and team performance of the groups they take part in increased with the number of female peers[142]. These results may be indirectly linked to social belongingness, which has been already highlighted in the case of secondary education.

Concerning peer interaction in student groups, a crucial parameter seems to be the time allowed to females for talking with peers. A counter-stereotypical video intervention (women talked longer and presented more technical information than men) was found to have a marked effect on peer interaction and equalize the time women and men spoke in a STEM group task undertaken by mixed-gender teams as opposed to the control condition (roles between women and men reversed), where men spoke significantly more[143]. Being given the opportunity for equal participation in collaborative work seems to foster female confidence.

A last point referring to peer interaction while undertaking collaborative work is related to peer assessment, which was suggested in the former section as a learning strategy for empowering female students and supporting their autonomy and self-regulation in the learning process. A quite interesting study was performed involving male and female students in engineering and CS, who were engaged in providing peer feedback by completing peer reviews[144]. The results were illustrative of the effect of

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[138] Perez-Felkner et al. (2019), p. 22; data used were from a nationally representative longitudinal cohort in the USA with 5210 college students.

[139] Gayles & Ampaw (2014), p. 461.

[140] See, in this regard, Barabino et al. (2020); p. 282.

[141] Cheryan et al. (2019); three studies are reported with undergraduate students in the USA.

[142] Niler et al. (2020), p. 150; the study involved 43 female students and 52 male students working in teams at a university in the USA.

[143] Lewis et al. (2019), p. 567, 572; the study involved 143 undergraduates majoring in STEM disciplines, mainly engineering, in a USA university.

[144] Lane et al. (2019), page 450-451; the study involved 109 undergraduate engineers and CS majors at a university in the USA.

anonymity on the ability of female students to include critical comments in their peer reviews, which was much more evident than the analogous effect on male participants, meaning that female students were more sensitive to anonymity than their male colleagues. It seems that anonymity let females surmount the injunctive norms that may impose a type of self-censorship in male-dominated STEM environments. Ideally, we may wish that critical and constructive feedback is not provided only under conditions of invisibility, but that it is enacted and tolerated overtly as a prerequisite of collective improvement. Nevertheless, an adequate configuration of a peer assessment setting with anonymous reviews may pave the way to such an ideal future, just like the double-blind peer review process utilized in most scientific journals.

5.4. Gender and grants in academia

The extant literature provides conflicting evidence on whether gender affects peer reviewing for grant proposals. In particular, large meta-analyses of studies on gender bias in peer review of grant proposals, based on 10,023 reviews by 6233 external assessors of 2331 proposals from social science, humanities, and STEM-related disciplines, showed that there were no gender differences in the peer reviews[145]. Similarly, an empirical investigation using the example of the Austrian Science Fund, based on 8,496 research proposals across all disciplines, included STEM-related ones, which were rated by 18,357 external reviewers in 23,977 reviews, showed that the final decision about the grant proposals was not associated with any gender bias. However, the decisions on the grant applications showed "a robust female reviewer salience effect. The approval probability decreases (up to 10%), when there is parity or a majority of women in the group of reviewers"[146]. A study by the European Research Council (ERC), which involved a cohort of 355 grantees from the Life Sciences domain, also showed no gender bias in the corresponding grant proposal processes[147].

On the other hand, a number of studies in the health/medical disciplines, based on data from different countries, have shown that the peer reviewing process is gender-biased[148]. The primary cause is attributed once again to the male dominance in these domains, which results in an underlying bias that affects the whole grant application process[149]. Bias emerges at different stages of the grant request pipeline, starting with the application (e.g., the majority of applicants are men), moving on to the evaluation process (e.g., the majority of the reviewers are men), and ending with the final decisions (e.g., the majority of grant recipients are males). Of course, the peer review is the most important stage, but it is also the stage that has been criticized the most, particularly in relation to gender bias[150].

It is important to identify as early as possible any gender biases in grant application processes, since "securing less funding slows career progression for women and reduces opportunities for publishing and other forms of collaboration, which are criteria for professional advancement"[151]. Such a negative impact on women's careers results in an underrepresentation of females at higher levels of academic

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[145] Marsh et al. (2011).

[146] Mutz et al. (2012), p. 121.

[147] Pina et al. (2019).

[148] e.g., Alvarez et al. (2019); Biernat et al. (2020); Ginther et al. (2016); Tricco et al. (2017).

[149] Morgan et al. (2018).

[150] Biernat et al. 2020; Sandstrom & Hallsten (2008).

[151] Morgan et al. (2018), p. E487.

hierarchies, despite increasing numbers of women admitted to universities, which in turn affects negatively the allocation of funding internally at an academic institution[152].

Alvarez et al.[153] made some recommendations for overcoming bias barriers concerning grants. First, they suggested that any descriptions, such as the guidelines for the proposal and the reviewers, should be written in genderless terms. Second, any salary gaps between females and males should be challenged. Third, recommenders should be asked to address an applicant's objective research record and avoid references at a personal level that are unrelated to the grant. And fourth, any use of ratings must be independent of any biased criteria.

Morgan, Hawkins, and Lundine argued in favour of first transforming academia before attending to peer review processes[154]. Specifically, they suggested that such a transformation "should aim to shift traditional gender norms through institutional policies that recognize gender bias and act to counter it". In addition, they argued in favour of funding further research investigating issues of bias in grant proposals, in both a quantitative and a qualitative manner. The quantitative studies would "allow us to understand the scale of the problem", whereas the qualitative studies would enable us to get a "greater understanding of the motivations, incentives and reasoning underpinning gender bias and its ramifications"[155]. The same researchers praised any efforts at funding such studies. The European Commission is among the organizations that have funded such projects in an attempt to further institutionalize and incentivize efforts toward gender equality.

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[152] Ovseiko et al. (2016).

[153] Alvarez et al. (2019).

[154] Morgan et al. (2018), p. E488.

[155] Morgan et al. (2018), p. E488.

6. EMPLOYMENT[156]

6.1. Figures and trends for female employment

6.1.1. The European context

There have been several trends in the EU during the last ten years that move towards narrowing the gender gap in STEM employment. With regard to the government sector, there was a growing percentage of female researchers between 2008 and 2015 in the field of engineering and technology in 15 out of 30 European countries for which data are available, and in the field of natural sciences, in 20 out of 31 European countries[157]. Although the proportion of women employed as scientists and engineers in the EU-28 (40.8%) remains lower than that of men, there has been a mean annual increase of 2.9% in number of females in this field between 2013 and 2017, while the growth rate observed for women was higher than the respective rate for men[158]. Another encouraging figure is that the proportion of women (around 44%) is much higher than that of men (around 29%) in knowledge-intensive activities, namely, activities where employees with tertiary education comprise more than one-third of the total number of people employed[159]. However, the percentage of women in ICT careers still remains relatively low, and it is currently below 2% of the women's total share in the European labour market[160].

6.1.2. The special case of Computer Science

Recent research in the USA has documented that women holding a degree in CS or engineering were not as likely as their male colleagues to persist in the workplace, widening the gender gap[161]. A study concentrated on the Silicon Valley technology industry, with data analysis covering the period from 1980 to 2015, revealed that the gender gap in CS increased[162].

6.2. Women face disproportionally more obstacles in their careers than men

Gender differences in STEM primarily originate from the global disparity for females concerning family life, including fertility treatment, pregnancy, childcare, and the often unequal load in housekeeping[163]. The effect of marital status and number of dependents on the duration of female careers is clearly negative, in contrast to males, where the listed factors were found to have a positive association with the number of years males had spent pursuing the same careers[164].

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[156] The key findings reported in this chapter are presented in Annex IV, in the form of a SWOT template.

[157] She Figures 2018 (2019), p. 84.

[158] She Figures 2018 (2019), p. 6, 37.

[159] She Figures 2018 (2019), p. 42-43.

[160] Fatourou et al. (2019), p. 54.

[161] Sassler, Michelmore, et al. (2017); data used were from the National Science Foundation's Scientists and Engineers Statistical Data System, from 1995 to 2008.

[162] John & Carnoy (2019); the study used data referring to the Silicon Valley technology industry from 1980 to 2015.

[163] Greider et al. (2019), p. 695.

[164] Xu (2015), p. 512-513; data used were from the Baccalaureate and Beyond Longitudinal Study with a representative sample of 11190 graduating seniors in all majors in the USA starting as a base-year cohort in 1993 and then being surveyed three more times, in 1994, 1997, and 2003.

The institutional arrangements that have been introduced to address these obstacles may provide valuable support[165]. Besides maternity leave, additional benefits compensating for female family obligations may include the stoppage of tenure clocks as well as on-site child care[166]. No matter how many and how widely used, the current measures do not seem enough to fully compensate for all impacts experienced, especially the differential needs introduced for women and men after having a child. For instance, the implications of making use of employment benefits such as parental leave were found not to be gender-neutral, since the need for female parental availability will remain relatively increased even after the leave period expires[167]. Indeed, it has been stressed that making use of maternity leave may backfire, due to the prolonged absence from work[168]. Such differential pressure on female careers often results in a deliberate demand for career change, voiced by women themselves, which is accompanied by lower expectations of prospects for one's career and related income. Future research needs to examine the potential of flextime and telecommuting to further assist women in restoring their career trajectories and choices after giving birth. Since these methods have both found to increase desirable flexibility in working conditions without compromising performance, they may allow for the creation of workplace environments that can boost gender parity by improving the work-life balance for women[169].

6.3. Women in upper-level positions and gender salary gaps

Two major aspects reflecting gender discrimination are the proportion of women in upper-level positions and gender gaps in salaries. A frequently observed trend is that women decrease in number as one moves upwards in positions. For example, this has been underlined for grade A staff in the natural sciences (18.1 %), and especially in engineering and technology (12.0 %)[170,171]. For the physical sciences and across STEM decision-making positions, the proportion of women is comparatively low[172]. The declining percentage of females at higher positions seems to create a positive feedback loop with adverse effects on female recruitment. Recent research has shown that the higher the proportion of females in administration in academia, the more the need for female recruitment and retention in STEM is endorsed[173].

Besides the relatively lower odds of advancing in one's STEM career, another gender difference concerns earning profiles, which is already discernible within the first 10 years of employment in the USA, and which is further augmented by marriage and number of dependents[174]. High-achieving men benefit more from STEM majors than high-achieving women, as far as their earnings are concerned[175]. Quite interestingly, research in different socio-cultural contexts and workplaces showed that there is a

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[165] Greider et al. (2019), p. 694.

[166] Wang & Degol (2017), p. 15.

[167] Holth et al. (2017), p. 238; the study involved interviews with 11 female and 11 male engineering graduates employed by a Swedish IT consultancy.

[168] Yoshikawa et al. (2018), p. 308.

[169] Miner et al. (2018), p.284.

[170] She Figures 2018 (2019), p. 115.

[171] See also in this regard Barabino et al. (2020), p. 284.

[172] She Figures 2018 (2019), p. 37.

[173] Williams et al., (2017), p. 1, 4, 11; the study involved 334 administrators at public and private research universities in the USA, including provosts, deans, associate deans, and department chairs in STEM fields.

[174] Xu (2015), p. 489, 513.

[175] Olitsky (2014), p. 266; the study used data from the ACT Alumni Outcomes Survey with 93229 college alumni across colleges and universities in the USA.

considerable lack of transparency about these salary gaps. In the UK and New Zealand, there was a pay gap for female employees in ICT compared to their male colleagues even at the start of women's careers, which could not be explained by qualification or position in the industry, and which was attributed to non-transparent pay and reward systems[176]. In an analogous study in Japanese academia, the gender salary gap was reported to reach up to 6%, even when rank and publication productivity were controlled for, which was not based on marital status or bargaining power, and which took the form of a bonus added to one's salary[177].

6.4. How far gender discrimination can penetrate: Unintended gender differences in the delivery of social media ads for careers

It is unimaginable how far gender discrimination can penetrate. Recent research has documented how gender differences and unintended discrimination may even be detected in the case of social media ads. A field test revealed that an advertisement for STEM careers, which was designed to be gender-neutral in its delivery, was less likely to be shown to women than men[178]. This difference was not because women were less likely to click on the ad, since the exact opposite was revealed: When women were shown the ad, they were much more likely than men to click on it. The difference was attributed to the fact that social media advertisers tend to bid more to advertise to women than men, specifically, about 5 cents more, since women were found to be more likely to convert after being presented with an ad, especially in the 25- to 34-year-old cohort. "Conversion" here refers to further action taken after encountering an ad, which is indicative of a user/potential consumer interacting with an ad, and which is a measure of the cost-effectiveness of the ad for the business that is being advertised. For instance, when a user/potential consumer adds an item to their shopping cart upon arrival to the website, then they are "converted". Given the relatively higher propensity of women for conversion as compared to men, women are more expensive to advertise to in social media, meaning that a lump sum invested in an ad may end up reaching more men than women. Since the algorithm used to deliver the ad for STEM careers in our example was not developed so as to take into account the above imbalance between women and men, the ad was unintentionally shown to more men than women.

Although more research is needed to consolidate and generalize these findings, they are illustrative of the broad socio-economic and socio-structural determinants of gender differences, which may more or less touch upon individual preferences and choices, but which can never be fully grasped or combated on the individual level of analysis. A major issue to be elaborated upon is that there can be instances of unintended gender discrimination, to the detriment of female candidates for STEM jobs. The social media ad market may skew ad delivery indented to be gender-neutral due to prizing female "eyeballs", since females are expected to yield higher return on unit of investment, and therefore, advertisers are willing to pay more for displaying ads to female eyeballs. This difference creates a bottleneck for female candidates for STEM jobs, since it favours male eyeballs, which are "cheaper". Using standard terminology of the social media ad market, the skewness leading to the bottleneck is related to the number of "impressions" (defined as the number of times an ad has been displayed on social media, i.e., frequency of delivery of an ad by social media browsers), and not "reach" (defined as

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[176] Belgorodskiy et al. (2012), p. 719; the study involved 426 online responses to a survey instrument and another 84 interviews and focus groups in UK and New Zealand from women working in ICT.

[177] Takahashi et al. (2018), p. 261; the study involved 1636 responses from university faculty in Japan.

[178] Lambrecht & Tucker (2019), p. 2970-2971; the study undertook a field test on Facebook using an ad promoting STEM careers targeted at women and men over 18 years old in 191 countries; all information presented in this section comes from this study.

total number of clicks, which reveals the number of people who eventually see the content of the ad). Indeed, females were more likely to click on the ad once they were shown it, that is, it yielded a relatively increased ad click rate, which is itself a manifestation of the differential gender conversion already referred to above.

6.5. Differential gender responses to gender bias in employment

Although males may acknowledge the additional struggles and hardships women need to put up with at their workplace, as well as male privileges[179], it is quite interesting to examine how justification of gender bias differs between women and men. Recent research has revealed that male respondents were more likely to disagree with scientific evidence justifying gender bias and to deny the existence of gender bias, overall; when males accepted this evidence they were more likely to give biological explanations to justify it, focusing more on innate gender differences rather than socio-economic factors[180].

Exposure to gender bias (a news article presenting science faculty members rating a male lab manager applicant as more competent and hireable than an identical female applicant and offering him a higher starting salary) has been found to lead to decreased sense of belonging, positive attitudes, and aspiration to participate in STEM for female respondents as compared to male respondents[181]. When participants were exposed to conditions of gender equality, however, these differences were offset, suggesting that female respondents could be as motivated as male respondents to engage in STEM if not discouraged by gender bias. Additional analyses showed that the effect of bias (number of reported gender bias/discrimination complaints for a hypothesized chemistry department) on intention to engage, which produced a clear gender gap, was driven by sense of belonging and anticipation of discrimination, which were adversely influenced by experiencing bias, and which in turn were associated with less positive attitude and trust towards the institution presented to respondents.

6.6. Gender diversity propels performance

Various research findings corroborate the beneficial effect of gender diversity on team performance. Increasing female representation in teams was found to enhance team identification for female team members, facilitating their psychological attachment to and confidence in the team, and further, fostering collective efficacy and team performance[182]. These findings implied that female participation should not just be indicative of mere female presence in teams, but should be quantitatively pronounced so as to trigger the above-mentioned beneficial effects. Moreover, gender diversity was found to favour the potential for innovation for technological companies[183], while having full-time female workers in the workforce was found to have a positive influence on capacity utilization[184]. These positive effects of gender diversity were also validated at the country level, where gender equality was

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[179] Sattari & Sandefur (2019), p. 172; the study involved 30 male faculty in STEM departments at two universities in the USA.

[180] Moss-Racusin et al. (2015), p.203-204; the study analysed 831 written comments by members of the public left at three websites in response to a scientific article reporting on science faculty gender bias, for which gender of the commenter was identified in 423 cases.

[181] Moss-Racusin, Sanzari, et al. (2018), p. 656; the study reports on two experiments, one with 322 adults fluent in English, residing in the USA, and recruited via MTurk, with 180 women among them; and a second experiment with 429 adults fluent in English, residing in the USA, and recruited via MTurk, with 224 women among them.

[182] Niler et al. (2020), p. 151.

[183] Botella et al. (2019), p. 2.

[184] Yeo & Grant (2019), p. 137; the study used industry data from the 2015 World Bank Enterprise Survey.

positively correlated with innovation capacity[185], and where gender equality is further expected to have a series of positive impacts on the GDP of the EU, the competitiveness and balance of trade of the EU economy, and job supply[186].

With regard to decision-making bodies and board composition, board gender diversity yielded higher firm performance when there was a critical mass of women on the board[187]. Above such a critical mass point, gender diversity reinforces performance, probably because it is accompanied by a corresponding heterogeneity of knowledge, attitudes, and experience, which all increase the pool of eligible options and alternatives to be discussed and pursued. Although further research is needed to validate these findings, there is a clear indication that gender diversity has a positive impact on board dynamics and propels firm performance. However, we need to note at this point that only six EU-15 and another two EU-13 have prepared guiding targets for gender balance in decision-making bodies[188], which implies that institutional provisions need to be put in place at a much higher pace.

6.7. Institutions established to close the gender gap

Tables 1 and 2 present several institutions established and initiatives undertaken to close the gender gap in STEM, ICT, and the digital sector in the USA and Europe, respectively. The tables provide a synopsis of the main objectives and activities prioritized by each institution in terms of engaging and mentoring women as well as concrete initiatives taken to consolidate paths from education to the workforce or combating inequality within the workforce (last column of Tables 1 and 2). Although the content of Tables 1 and 2 is only indicative of institutions and the initiatives undertaken by each institution to address the gender gap, and is not intended to provide a full account of all relevant cases, there are striking differences between the two contexts. First, it seems that the repertoire of institutions in the USA is much richer and involves multiple forms of action taken in terms of engaging women at the individual level of reference, providing mentoring as well as promoting gender equality in the workforce. In addition, European institutions committed to promoting equality in STEM, ICT, and the digital sector are much more stakeholder-based and organized as networks of actors in a top-down fashion. Although this should not be taken as a disadvantage, on its own, there seems to be a lack of vertical connections providing linkages from local contexts to decision-making bodies with a mandate to recommend top-down policies. It may be that this is left to Member States alone to regulate. In that case, however, multi-stakeholder schemes operating at the EU level may lose sight of the numerous experiences gained in local contexts and thereby may not be able to profit fully from an inter-contextual comparison of lessons learnt. In sharp contrast to the European context, the character of most initiatives in the USA reflects a grassroots origin and any networking is then built upon this grassroots character. The connection of the network with the local contexts, from which the whole initiative originates, is thereby sustained.

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[185] ERAC SWG on Gender in Research and Innovation (2018), p. 9.

[186] European Institute for Gender Equality; https://eige.europa.eu/gender-mainstreaming/policy-areas/economic-and-financial-affairs/economic-benefits-gender-equality

[187] Wiley & Monllor-Tormos (2018), p. 298, 302; the study involved a sample of 1605 firm-year observations representing 236 Fortune 500 firms in the Science, Technology, Engineering, Mathematics, and Finance sectors.

[188] ERAC SWG on Gender in Research and Innovation (2018), p. 30.

Table 1: Institutions/initiatives aiming to address the gender gap in STEM in the USA

Institution	Engagement	Mentoring	Workforce
National Science Foundation (NSF), ADVANCE program	Fund and support the ADVANCE Resource and Coordination (ARC) Network	Maintain a research hub on leadership and recognition with plenty of role model examples	Promote STEM equity in academia by grants awarded to intersectional approaches
Association of Women in Science (AWIS)	Provide ongoing support to the ARC network as its backbone organization	Provide support for personal development through leaders' communications	Global network connecting together more than 100,000 professionals in STEM
American Association of University Women (AAUW)	Provide education and training, including resources, advocacy, and salary negotiation training		Discrimination at workplaces challenged by Legal Advocacy Fund
Girls in Tech	Offer coding courses, bootcamps, hackathons, and start-up competitions to women	Girls in Tech Mentorship Program, focusing on technology and entrepreneurship	Non-profit working to do away with gender inequality in high-tech industries/start-ups
National Institute for Women in Trades, Technology and Science	Provide online professional development in the form of trainings, bootcamps, webinars		
Million Women Mentors (MWM)		Sustain a growing network of over 1 million mentor relationships for careers/leadership	
Change the Equation	Improve STEM learning for every child, with particular focus on girls and students of colour	Promote leadership by means of conferences, awards, and research-proven approaches	National coalition of 110 corporate CEOs at the intersection of business and education
Girls Who Code	Address the gender gap in technology by offering learning opportunities for students/alumni	Address the gender gap in technology by offering a sisterhood of peers and role models	Address the gender gap in technology by offering pathways into the computing workforce

Institution	Engagement	Mentoring	Workforce
National Girls Collaborative Project	Maximize access to resources for participation in STEM through local collaboratives		Create in each state a network of professionals, researchers, and practitioners

Note: The info presented was taken from Miner et al. (2018) and Barabino et al. (2020), and supplemented by an online search; the content in the table reflects only these institutions and the initiatives undertaken by each institution to address the gender gap in STEM, ICT, and the digital sector; it is not intended to provide a full account of all relevant cases.

Table 2: Institutions/initiatives aiming to address the gender gap in STEM in Europe

Institution	Engagement	Mentoring	Workforce
European Centre for Women and Technology (ECWT)			Multi-stakeholder partnership with governments, business, academia, and non-profits
European Network for Women in Digital			Foster partnerships to enhance female participation in the digital sector across the EU
European Institute for Gender Equality (EIGE)			Gender Equality in Academia and Research (GEAR) Tool for research organizations
Standing Working Group on Gender in Research and Innovation			Group with advisory role in policies for gender equality in Research and Innovation

Note: The info presented was taken from Fatourou et al. (2019) and supplemented by an online search; the content in the table reflects only these institutions and the initiatives undertaken by each institution to address the gender gap in STEM, ICT, and the digital sector; it is not intended to provide a full account of all relevant cases.

A way to compensate for this double lack may be to equip or cross-fertilize the current multi-stakeholder partnerships operating in the EU with horizontal networks of actors (1) operating much closer to the local context, and actors (2) who would strengthen the linkages between education and the workforce. Examples of such networks are the European Schoolnet (network of 34 European Ministries of Education), the European Teacher Education Network, The European Education Policy Network on Teachers and School Leaders, the European School Heads Association, ECSITE - European Network of Science Centres and Museums, and so forth. The contribution of research projects funded by the EU should also be exploited in this direction.

The idea of multi-stakeholder platforms may be quite insightful for operationalizing this broadening of partnerships. Such a platform has been already established with a focus on the European Research Area (ERA), for instance. Stakeholders in the ERA Platform (e.g., the European Association of Research and Technological Organisations – EARTO; the European University Association – EUA; the League of European Research Universities – LERU; Science Europe; the Conference of European Schools for Advanced Engineering Education and Research – CESAER; EU-Life) may also be considered as candidates for enriching current initiatives for networking and setting up a new platform concentrated on addressing the gender gap in STEM, ICT, and the digital sector. This platform may have a decisive role in terms of (1) balancing between vertical and horizontal approaches at the EU level (e.g., screen fruitful experiences gained at local contexts and scale up good practices for closing the gender gap in STEM); (2) detecting and supporting successful trajectories for females from education into the workforce; (3) outlining indicators for monitoring policy implementation. A crucial note here is that there is not much meaning in adding another consultative or advisory body on top of the already existing institutions. Instead, the suggested platform would make a marked contribution if it achieved a constructive role in delivering concrete outputs in terms of the three points just highlighted. Such an arrangement and operation would, on the one hand, develop an urgently needed toolkit of good practices, pathways from formal education to the workforce, and indicators for monitoring policies to address the gender gap in STEM, ICT, and the digital sector, and, on the other, leave as much flexibility and autonomy as possible to each Member State for configuring and fine-tuning their own approaches.

7. EXAMPLES OF GENDER BIAS AND INEQUALITIES FROM THE DIGITAL SECTOR: THE CASES OF ARTIFICIAL INTELLIGENCE AND CYBERSECURITY

In this section we present examples of gender bias and inequalities from the digital employment sector.

Despite the efforts for almost two decades to remove gender bias and inequality from the digital sector (e.g., digital technologies, CS, IT, ICT), insufficient progress has been made[189]. The gender gap between females and males continues to exist across all digital technology domains[190], with Artificial Intelligence (AI) and cybersecurity being among the domains with the largest gaps. The average percentages of females in AI and cybersecurity, worldwide, are 12%[191] and 20%[192], respectively.

This gender disparity in the digital sector is the result of the underrepresentation of girls and women in computer science (for a thorough review of the past four decades, see Sax et al., 2017). The extant literature has been shedding light on this phenomenon for over two decades now, but the problem still persists[193]. Among the reported causes are: (a) girls feel that they do not belong in computer science courses, as opposed to boys, due to weaker feelings of fit with computer science stereotypes, for example, most computer science teachers are males[194], (b) girls have a tendency to be less confident than boys when attending a computer science class[195], (c) girls evaluate their own computer science capabilities lower than boys do, even when they perform similarly[196], (d) girls are less positive in foreseeing themselves in computing careers than boys[197], and (e) girls attribute undesirable, stereotypical characteristics to the computer science domains, such as, masculine, “geeky,” and isolating[198].

Obviously, this imbalance of gender representation in the digital sector creates inequality, which in turn marks a male-biased trajectory for the digital sector in the foreseen future. The questions to be raised at this point are: “Why does the gender gap still persist in the digital sector?”, “What are the causes?”, and “What measures need to be taken in order to eliminate this gap?” Just below we discuss, the cases of the AI and Cybersecurity domains, based on the extant literature, in an attempt to find answers to these questions.

7.1. The case of Artificial Intelligence

One of the rising STEM-related domains is Artificial Intelligence (AI). AI falls under the computer science discipline and focuses on the development of intelligent machines that simulate human thoughts and actions. For instance, AI focuses on reasoning, problem-solving, learning, perception and planning.

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[189] Sax et al. (2017); Shade (2014).

[190] GAFAM: Women still underrepresented in tech.

[191] Simonite (2018).

[192] Morgan (2019).

[193] DuBow et al. (2016); Jethwani et al. (2017).

[194] Ashcraft et al. (2012); Master et al. (2015).

[195] Shapiro & Williams (2012).

[196] Cooper, 2006; Shapiro & Williams (2012).

[197] Christensen et al. (2014).

[198] Cheryan et al. (2013); Shumba et al. (2013).

Russell and Norvig[199] simply stated that AI is relevant to any intellectual task. Obviously, AI is intertwined with many of our current digital innovations, ranging from *weak* AI (e.g., gaming) to *strong* AI (e.g., robots, self-driving cars). For example, we regularly interact with AI artefacts, such as personal digital assistants or chatbots, which are implanted into devices we use on a daily basis (e.g., smartphones). It is foreseen that AI will be strongly entangled with humans' future lives, ranging from AI assistants and professionals/specialists to AI friends and companions, which also explains the emphasis placed on AI by academia and industry[200]. According to the World Economic Forum[201], AI is among the leading drivers of innovation across industries.

Despite its added value, AI comes with a number of weaknesses[202]. One of the most critical weakness relates to all sorts of different types of biases (e.g., gender, race, sexual orientation). Of course, any investigation of any type of bias in AI should take into account that these biases are the result of humans' already inherent biases. The AI artefacts (e.g., models, systems) we construct and train are a reflection of their creators. In this section, we aim to discuss how gender and AI intersect and what challenges and bias emerge, which in turn affect gender equality in the AI domain.

According to Ferrando, "the seeds of the futures are gendered, in the ways they are currently being conceived and actualized"[203]. In this respect, gender could stereotype AI in a way that it reflects the current gender related characteristics and personal and societal beliefs and norms (e.g., daCosta[204]). For instance, it is widely acknowledged that the current male dominance in the AI domain[205] has established male stereotypes across AI artefacts (e.g., cyborgs, robots). For instance, Apple was heavily criticised in 2014 when its health application failed to include the ability to track a woman's menstrual cycle[206]. Additionally, it does not appear to be random that robots for chatting and companionship, such as Sophia by Hanson Robotics and Erica by Hiroshi Ishiguro, are females, whereas robots for rescuing and doing parkour, such as Hermes from MIT and Atlas from Boston Dynamics, respectively, are males. Such practices of gender stereotyping contribute to the already existing gender gap, and if left unattended could further exacerbate the already existing gender inequalities in AI and in STEM in general.

7.1.1. Gender representation in AI

According to recent calculations by the World Economic Forum and the LinkedIn Economic Graph Team, there is a significant gender gap among AI professionals. In particular, only 22% of AI professionals globally are female, compared to 78% who are male[207]. The countries with the largest gaps are Germany, Brazil, Mexico and Argentina, whereas the countries with the smallest gaps are Italy, Singapore and South Africa.

Such figures reveal a tenacious structural gender gap among AI professionals, which is in accordance with the broader gender gaps within the computer science/IT, ICT, and STEM disciplines and within historically male CS industries such as the hardware industry, the software industry and the networking

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[199] Russell & Norvig (2010).

[200] Dale (2016).

[201] World Economic Forum (2018).

[202] Daugherty et al. (2019).

[203] Ferrando (2014), p. 42.

[204] daCosta (2018).

[205] World Economic Forum (2018).

[206] Alba (2015).

[207] World Economic Forum (2018).

industry.[208] In addition, traditionally female sectors whose future might depend upon AI, such as health care, are foreseen to become "male-dominated" (due to lack of expertise in AI by females).

7.1.2. How does gender bias appear in AI and what causes this bias

Our literature review found three distinctive ways that gender bias appears in AI:

AI gender is stereotyped

AI assistants are often assigned traits or features to resemble humans, but this anthropomorphization procedure appears to be skewed towards the feminine side when it comes to roles that historically have been assigned to women[209]. For example, the first major commercial AI assistant projects, such as Siri (Apple), Tay (Microsoft) and Alexa (Amazon), are females. On top of the names, voices and/or avatars assigned to these assistants, they were also assigned behaviours following gender stereotypes that reinforce traditional assumptions of femininity[210].

On the other hand, a male robot is usually given more agentic characteristics and is assigned male-stereotyped tasks[211]. Recent studies have shown that gender stereotypes are so deeply rooted within people that they continue to shape people's judgments when it comes to robots and AI in general. In particular, when a male robot fits the gender stereotypes, it is still selected for performing masculine tasks, even if its technical characteristics are acknowledged and are not adequate for achieving the tasks (e.g., Dufour & Ehrwein Nihan[212]).

While this has created critical talk around representation in AI, no solutions have as yet been reported in the literature. On the contrary, this talk has raised a number of questions revolving around the gender of AI, such as: Can AI be developed to be genderless? If not, how do we ensure that all genders are represented, both in voice and visually, in order to develop socially responsible AI?

Underlying gender bias in AI

It has been documented that AI carries an underlying gender bias, since it has predominantly been designed by males. Specifically, the bias originates from datasets that have been created by males and, thus, underrepresent or misrepresent other groups, including females[213]. Needless to say, any AI model training based on such data results in biased AI. Bias could occur not just for women, but for other non-binary social groups (e.g., related to ethnicity, LGBTQ+ people). An example of such faulty databases was found in the facial recognition domain, where the various AI models were found to have higher error rates for women's faces and for people with darker skin tones. Another example of such faulty databases was found in the early stages of automatic speech recognition (i.e., speech-to-text technology). Specifically, automatic speech recognition was found to be ineffective for females as compared to males[214]. Needless to say, both of these examples highlight the influence that databases have on AI systems. Biased databases result in biased AI systems and models[215].

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[208] World Economic Forum (2018).

[209] daCosta (2018).

[210] daCosta (2018); Weber (2005); Hester (2016).

[211] Eyssel & Hegel (2012); Tay et al. (2013).

[212] Dufour & Ehrwein Nihan (2016).

[213] Bolukbasi et al. (2016).

[214] Henton (1999).

[215] Bolukbasi et al. (2016).

Gender bias can also be found directly in natural language. Therefore, when natural language is used to feed AI directly, it can transfer its bias to AI[216]. The bias also emerges from word-embeddings, namely, words from the natural language that are converted to numerical representations, which are then used by AI models for natural language processing. Gender biases have been identified within online material, such as online news (e.g., Ross & Carter[217]) and web searches (e.g., Kay, Matuszek, & Munson[218]).

Gendered issues in the AI workplace

AI related jobs are male-dominated, which implies that most decisions concerning AI are being made by males. This fact by definition is a source of bias and inequality, since not all voices are heard and represented during decision-making processes concerning AI. Of particular note is that all of the major technology companies (i.e., Amazon, Apple, Facebook, Microsoft and Google) are male-dominated across their total workforce, their leadership jobs and the tech jobs, with the tech jobs being the field in which females are most underrepresented. Only approximately 23% of tech jobs were assigned to females.[219]

In addition, the gender gap in AI results in most AI-related development (e.g., patents, start-ups) being dominated by males. For example, only 1-2% of the start-ups funded by venture capital are managed by female founders in the last decade.[220] One explanation for this bias/inequality is the fact that venture capital concerns are primarily led by males, who apparently favour their own kind.[221]

7.1.3. Overcoming gender bias in AI

In an attempt to avoid gender bias in AI and to create a gender equal AI domain, researchers, analysts and entrepreneurs have suggested a number of practices to follow:

- Make the computer science and AI domains more attractive to females across K-12. For instance, some outreach educational programs have been designed for this purpose, which have shown success in attracting more females in AI (e.g., the SAILORS program[222]).
- Recruit more females in AI[223]. This could be achieved by developing a K-16 pipeline.
- Funding agencies and investors need to support more female founders who are starting an AI-related project or company.[224]
- Move towards genderless images of AI and robots[225], unless gender is a key factor for some reason.
- Use machine learning training datasets that come from diverse human samples[226]. If the criterion is solely gender, then a broader representation of gender variants should be used to enable us to understand how to handle the current and the future diversity.
- Ensure that humans labelling the training datasets come from diverse backgrounds[227].
- Attend to unfairness by collecting more training data associated with groups historically ignored[228].

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[216] Bolukbasi et al. (2016); Leavy (2018).

[217] Ross & Carter (2011).

[218] Kay et al. (2015).

[219] GAFAM: Women still underrepresented in tech.

[220] Zarya (2018).

[221] Zarya (2018).

[222] The Stanford Artificial Intelligence Laboratory's Outreach Summer -- SAILORS; for details, see Vachovsky et al. (2016).

[223] Feast (2019).

[224] Zarya (2018).

[225] Simonite (2018).

[226] Feast (2019).

[227] Feast (2019).

[228] Feast (2019).

- Mitigate gender bias in natural language processing[229].
- Determine gender-neutral words by removing the gender associations from *embeddings*[230]. Such AI tools already exist. For instance, the AI text editor Textio can rewrite job descriptions to attract candidates from groups that are not well-represented[231].
- Apply modern machine learning *de-biasing* techniques (i.e., removing multiple gender dimensions) that better guarantee fairness.[232] Overall, technical solutions for fair, moral and accountable AI should be established[233]. Approaches to modifying classification algorithms to define and achieve various notions of fairness have been described in a number of works[234].

Although identifying how gender bias and inequalities are enacted in AI and how these issues could be resolved is a significant first step, there are still many open questions to be answered. Beyond the remedies presented just above, both the academic/research community and the industry need to develop more general approaches in order to address the three basic biases, as outlined above (for more details, see Sections 8 and 9). In particular, we need to devote time and resources to addressing the societal biases that in turn feed AI and the digital sector in general. The goal is to have AI systems and models that embrace diversity and are fair and effective for all. The pros of AI will overshadow the cons if we address the current AI weaknesses cooperatively.

7.2. The case of cybersecurity

Research has revealed, on one hand, that the weakest link in a cybersecurity chain (i.e., the security of information and the systems and hardware that transmit, use, and store that information) is humans, regardless of their gender, and on the other hand, that the security behaviours of men and women differ[235]. For example, it was found that women have greater privacy concerns than males when surfing or working online[236], women have greater security policy compliance intentions than men[237], and women place more importance on perceived control and privacy risk when sharing data on social networking sites[238]. Anwar et al.[239] have shown that "there are statistically significant gender-wise differences in terms of computer skills, prior experience, cues-to-action, security self-efficacy and self-reported cybersecurity behaviour". Similarly, Fatokun et al.[240] found that security self-efficacy, computer skills and prior experience were among the cybersecurity scores that were impacted by gender. Evidently, such findings suggest that males and females perceive cybersecurity in different ways, which in turn results in different cybersecurity beliefs and behaviours[241].

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[229] Sun et al. (2019).

[230] Bolukbasi et al. (2016); Leavy (2018).

[231] Daugherty et al. (2019).

[232] Schmidt (2015).

[233] Barocas & Selbst, 2016; Savulescu & Maslen (2015).

[234] Dwork et al. (2012); Feldman et al. (2015); Hendricks et al. (2018).

[235] Gratian et al. (2018); Sasse & Flechais (2005).

[236] Hoy & Milne (2010).

[237] Ifinedo (2014).

[238] Hajli & Lin (2016).

[239] Anwar et al. (2017), p. 440.

[240] Fatokun et al. (2019).

[241] Anwar et al. (2017).

Even though gender is an important factor to understand and handle when it comes to cybersecurity, only about 20%[242] of cybersecurity personnel are female, worldwide. This gender gap could potentially result in ineffective cybersecurity, since female perspectives would be absent from decision-making processes concerning cybersecurity[243]. In other words, females and males have several distinct perceptions and follow different courses of action with respect to their cybersecurity behaviours, which, if not understood and taken into consideration, will lead to unproductive cybersecurity practices[244]. A diverse set of clients/users requires a diverse set of cybersecurity professionals in order for the clients' voices and needs to be heard and understood, which in turn would also lead to more effective cybersecurity.

Someone could reasonably wonder at this point why fewer females than males are employed in the cybersecurity sector, especially, when considering that diversity results in more effective cybersecurity and that we face a severe shortage of cybersecurity professionals worldwide.[245]

7.2.1. Why fewer females select cybersecurity for employment

The primary reason for having fewer females in cybersecurity has its roots in the low numbers of girls showing interest in STEM fields and especially in computer science by the end of high school[246] (for details, see also Section 5.1.2). Bagchi-Sen, Rao, Upadhyaya, and Chai[247] attributed the limited interest in cybersecurity to social/institutional and personal parameters that negatively affect females across their K-16 education and when making their decisions about a career.

Social/institutional barriers

There are several social and institutional factors negatively affecting selecting, starting and maintaining a career in cybersecurity for females. The most important ones relate to the perceived nature of the work and the small percentage of women involved in this sector, starting in schools and continuing all the way up to the workplace. Specifically:

- Male teachers and other personnel dominate computer science and IT in schools and, later on, in universities and in the workplace; thus, female students are less inspired (absence of role models) and have limited guidance and mentoring opportunities. The Computing Research Association – Widening Participation (CRA-WP) program exemplifies the significance of mentoring and the necessity for additional opportunities.[248]
- The cybersecurity sector is also male0dominated, which makes selecting the sector for future undergraduate and graduate studies and employment less appealing for females[249].
- Cybersecurity involves long hours of work (e.g., when it involves real-time hacker attacks). The hectic work schedule was found to be less appealing for females who want to balance career and family[250].

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[242] Morgan (2019).

[243] Bagchi-Sen et al. (2010).

[244] Kearney & Kruger (2016).

[245] (ISC)^2 CYBERSECURITY WORKFORCE STUDY (2019).

[246] Sax et al. (2017).

[247] Bagchi-Sen et al. (2010).

[248] Computing Research Association – Widening Participation. Increasing the success and participation of underrepresented groups in computing research.

[249] Bagchi-Sen et al. (2010).

[250] Armstrong et al. (2007).

- Cybersecurity, as with the rest of the digital sector, is socially stigmatized/characterized as masculine, "geeky," and isolating, which is considered by females to be a major drawback[251].

Personal barriers

According to Bagchi-Sen et al.[252], there are several personal factors that end up being barriers for women selecting the digital sector, including cybersecurity, for a career. These factors involve the "educational background, personality traits, interests and abilities, IT identity, gender identity (such as which jobs are perceived as 'feminine' versus 'masculine'), and perceived self-efficacy -- in this case, a woman's belief in her ability to accomplish a task"[253]. They further argued that these personal characteristics are shaped by women's family and wider social environments. Families, for instance, play a prominent role as one of the earliest sources of influence on students' learning paths by serving as role models through their own occupational and workplace experience, and sending implicit and explicit messages regarding their children's future endeavours and careers[254]. Clearly, these family and social environments need to be attended to for any possible biases that could be feeding females' personal beliefs and perceptions concerning the cybersecurity domain.

Women's self-efficacy appears to be one of the strongest personal barriers. According to Hartzel[255], women tend to show lower self-efficacy in computer/IT skills, which results in their not selecting the digital sector for a career. This could be explained by the previous sections in this report, in which girls were found to show less interest in STEM and even lesser interest in CS/IT and ICT[256]. Having a strong background in both of these disciplines is a requirement for a cybersecurity career. In fact, along with experience in these domains, cybersecurity professionals need to have knowledge of hardware and software systems, the law, policy-making, internal and external regulations, and company and government policies. In addition, they should have a number of hard and social/soft skills[257]. Needless to say, absence of any of these further burdens a person's self-efficacy and, of course, their choice of a career in cybersecurity.

7.2.2. Overcoming the barriers to attracting more females to cybersecurity

One way to tackle the aforementioned social/institutional and personal barriers and to attract more females in the cybersecurity field, is to attend to girls' needs as early as when they have their first encounter with computer science classes. In most countries, computer science classes start at grade 7 (11- to 12-year-olds) and span until grade 12 (17- to 18-year-olds). A study by Jethwani, Memon, Seo, and Richer, investigating adolescent (16- to 19-year-old) girls' perspectives on the cybersecurity field revealed that "single-sex settings, encouraging teachers who focus on the process of knowledge, and the presence of female role models challenge stereotypes about the field itself [cybersecurity] and retain women and girls in the field [cybersecurity]"[258]. They further found that it is more beneficial for girls to study cybersecurity separately from other computer science domains, as there are exclusive aspects of the cybersecurity domain that girls find to be appealing. For example, they found that girls

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[251] Cheryan et al. (2013); Shumba et al. (2013).

[252] Bagchi-Sen et al. (2010).

[253] Bagchi-Sen et al. (2010), p. 26.

[254] Moakler & Kim (2014).

[255] Hartzel (2003).

[256] Sax et al. (2017).

[257] Bagchi-Sen et al. (2010).

[258] Jethwani et al. (2017), p. 17.

like cybersecurity (i.e., hacking, decoding) because “it is perceived as having real world and practical importance that requires creative and collaborative problem-solving strategies”[259].

Given these findings, Jethwani et al.[260] suggested two ways to challenge the already established gender norms and biases that restrict adolescent girls from electing to study cybersecurity and being employed in the cybersecurity domain. The first focuses on buffering stereotypes and building confidence, and the second focuses on portraying the unique appeal of cybersecurity.

In the case of “buffering stereotypes and building confidence”, Jethwani et al.[261] suggested that the already established stereotypes about computer science (e.g., computer science is for geeks, computer science is isolating in nature, computer science is for males), which also apply to cybersecurity, must be challenged and eliminated. In so doing, the following measures must be applied:

- Stereotypes related to male dominance (e.g., my computer science teacher is usually a man, most of my fellow classmates are boys), could be overcome by increasing the number of females within a computer science class, or even better by creating single-sex classes[262], and by hiring primarily female teachers for computer science classes attended by girls. The latter is vital, since research has shown that female teachers are more easily identified by girls as role models, which could also turn into a mentor-mentee relationship[263]. Additionally, single-sex, non-competitive classes were found to work better for building up the confidence of girls; for example, female peers are more encouraging[264].
- The teachers must be supportive, regardless of the gender of the student, and their teaching should involve solving practical problems via hands-on and applied activities. This approach was found to promote confidence among girls and women in IT[265]. Building confidence among adolescent girls in computer science classes is vital, since they were found to be more inclined to lose their confidence. The National Center for Women & Information Technology (NCWIT) Engagement Practices Framework suggests that to build females’ confidence, you need to “promote a ‘growth mindset’, provide feedback that helps students improve their performance, create opportunities for students to interact with teachers/faculty inside and outside the classroom, and mitigate stereotype threat by avoiding stereotypes and providing positive role models”[266].
- The learning process should be collaborative in nature and focus on real-life, problem-solving based activities[267]. The latter is needed to show that cybersecurity relates to authentic, everyday life situations and the collaboration part is needed to show girls that the stereotype that portrays the computer science professionals as nerds who are isolated for long periods of time is not valid.

As far as revealing the “unique appeal of cybersecurity”, Jethwani et al.[268] suggested that cybersecurity must be introduced to girls through authentic, real-life scenarios and problems/activities. In this way

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[259] Jethwani et al. (2017), p. 18.

[260] Jethwani et al. (2017).

[261] Jethwani et al. (2017).

[262] Jethwani et al. (2017).

[263] Ashcraft et al. (2012); Cheryan et al. (2013); Master et al. (2015).

[264] Jethwani et al. (2017).

[265] Werner & Denner (2009).

[266] DuBow et al. (2016), p. 76.

[267] Jethwani et al. (2017).

[268] Jethwani et al. (2017).

the girls will come to understand that cybersecurity is something important to all of us, especially when it comes to our personal and family privacy, our physical safety, our digital identities, and our national security. Another way to show girls that cybersecurity could be appealing to them is through engaging them in learning situations that involve collaborative and creative processes, such as collaborating with peers to solve a cybercrime. There is growing evidence that such cooperative, hands-on activities increase girls' interest in cybersecurity[269].

At the university level, Bagchi-Sen, Rao, Upadhyaya, and Chai[270] suggest that we could attract females by offering them scholarships and grants to study computer science and then focus on cybersecurity. At the workplace level, grants could be used for recruiting new female workers from multiple sources to grow the team from the outside in and, in the long term, train existing IT female professionals as cybersecurity experts to grow the team from the inside.[271]

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[269] Turner et al. (2014).

[270] Bagchi-Sen et al. (2010).

[271] (ISC)^2 Cybersecurity Workforce Study (2019).

8. MAIN DISCUSSION POINTS

In the following sections, we present the main discussion points that emerged from the literature review.

8.1. Biological, individual, and socio-cultural determinants of the gender gap

The first major discussion point is that either the previous research has not converged on the impact of biological factors on STEM performance and attitudes[272], or the contributions available are far from conclusive in justifying and consolidating that impact[273]. A meta-analysis of 227 studies covering over 1.6 million students from grade 1 and above validated that girls had higher average grades and lower variability than males[274]. A more interesting finding was that grade differences between females and males (both mean and variance) were lower in STEM than non-STEM subjects. Therefore, the variability hypothesis, positing that males' tendency to reveal higher variability than females for psychological traits results in comparatively fewer females with top ability, cannot suffice to explain the over-representation of males in STEM. Other gender differences highlighted by some studies, such as differences in learning style[275], do not seem to suffice for explaining the gender gap.

Overall, there are several indications pointing towards the primacy of socio-cultural factors over biological factors or factors at the individual level of reference in shaping STEM-related ability and interest[276,277,278,279,280]. Indeed, individual choices are made within a wider socio-cultural frame, which means that the decisions of individual women and men are always inscribed in and mediated by concrete socio-cultural contexts and cannot be examined in isolation, apart from these contexts[281]. Several illustrative examples of the mediating role of socio-cultural contexts were portrayed in the previous chapters, for instance, the salary gap for female employees as compared to their male colleagues, as well as the productivity gap with regard to publications by female scientists in academia. As long as the socio-cultural context does not change to favour gender equality in STEM, any change at the individual level will not be sustained in the long run[282]. Moreover, attributing the gender gap in STEM to women's individual choices risks blaming women themselves, and, at the same time, vindicating social structures and causes behind the construction of "gender" and gendered choices[283]. The contrast between biological inclination, on the one hand, and the socio-cultural frame, on the other, within which individual attitudes and behaviour are observed, is also reflected in the very difference between "sex" and "gender". While "sex" refers to differences in biology, "gender" denotes

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[272] Jungert et al. (2019), p. 493; the study involved 1597 high school and junior college students from Canada and Sweden.

[273] Wang & Degol (2013), p. 328.

[274] O'Dea et al. (2018), p. 3-4.

[275] Lau & Yuen (2010), p. 1098-1099; the study involved 121 female and 169 male students in grades 10 and 11 in Hong Kong who studied computer programming.

[276] Barabino et al., 2020; page 283-284

[277] Cheryan et al. (2017), p. 22.

[278] Wang & Degol (2013), p. 328.

[279] Wang & Degol (2017), p. 5, 11.

[280] Yoshikawa et al. (2018), p. 304, 306, 308.

[281] Miner et al. (2018), p. 281.

[282] Diekman et al. (2017), p. 164.

[283] Miner et al. (2018), 276, 279.

the multiple and complex socio-cultural determinants of women's and men's attitudes and behaviours. At this point we also need to underline that both women and men actively produce and reproduce gender-expected and actual roles in society, deliberately or not[284].

8.2. No magic wand to fix the gender gap

8.2.1. Interventions targeting individual participants may backfire

The incompleteness of explanations at the individual level of reference is reflected in the ineffectiveness of interventions targeting individuals. Specific interventions with multiple components, for instance, professionally produced and scripted videos on gender bias combined with an evidence-based module on gender disparities in the workforce, were found to increase awareness of bias without impairing self-efficacy to address this bias, both among the general population sample recruited as well as among STEM faculty, and this were reported for both female and male participants[285][286]. Despite their positive effects, however, which were replicated in subsequent research, these same video interventions were also found to decrease sense of belongingness in the sciences and increase self-reported social identity threat for female respondents; again, this occurred among women in the general population sample as well as among female scientists[287]. Although additional interventions can be designed and implemented to address these adverse effects, this whole process is reminiscent of medical treatment, which should be accompanied by additional medication aimed to remedy the adverse side-effects of the initial intervention. The above example is illustrative of how a well-designed and well-delivered intervention targeting individuals may backfire, unless backed up by a supportive socio-cultural context.

8.2.2. Interventions need to be delivered within real-world contexts

It seems that interventions should not be staged, but need to be delivered within real-world contexts. For instance, a quite interesting insight from past experience in special programs designed for encouraging female participation in CS studies and careers was that benefits derived by female participants from gender-focused activities were especially salient when these were presented naturally, meaning embedded in real-life contexts in the social environments, where interns would be expected to undertake the planned activities, instead of being explicitly packaged and delivered in a more rigidly and institutionalized arrangement, such as a diversity workshop[288]. In the former case,

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[284] Miner et al. (2018), p. 272.

[285] Moss-Racusin, Pietri, et al. (2018), p. 253-254; the study involved Video Interventions for Diversity in STEM-VIDS, which included two sets of videos with social psychological research findings on gender bias, namely, narrative videos with characters who had been negatively affected by gender bias in the sciences, and expert videos with a psychology professor being interviewed on gender bias; see https://academics.skidmore.edu/blogs/vids/. Experiment 1 involved 450 participants recruited in exchange for 3 USD on Amazon's Mechanical Turk; Experiment 2 involved 331 academic scientists scheduled to attend summer training on engaging and active science classrooms.

[286] Hennes et al. (2018), p. 797, 804; the study used VIDS, see https://academics.skidmore.edu/blogs/vids/, and a module with evidence-based information on gender disparities in the workforce was also used; Experiment 1: 343 participants recruited in exchange for 5 USD on Amazon's Mechanical Turk; Experiment 2: 130 faculty participants who were scheduled to attend summer training for engaging science classrooms and who completed three sessions of an experiment.

[287] Pietri et al. (2019); Experiment 1 involved 585 participants recruited in exchange for 3 USD from Amazon's Mechanical Turk website; Experiment 2 involved 508 participants recruited in exchange for 2 USD from Amazon's Mechanical Turk website; Experiment 3 involved 102 female academic scientists scheduled to attend summer training on engaging science classrooms.

[288] Kim et al. (2011); the study involved interviews with 20 program directors and evaluation assessments completed by 96 interns in "Research Experiences for Undergraduates", which are programs funded by the National Science Foundation in the USA to support women and underrepresented students of colour pursuing graduate studies and careers in science and engineering; "Research Experiences for Undergraduates" or REUs offer opportunities to interns for engaging in scientific real

female interns tended to better familiarize themselves with settings and tasks and take over the ownership of the process, with marked and long-lasting effects. We identified a related finding in the case of cybersecurity, which female adolescents were found to like exactly because of its real-world, practical importance, which needs to involve problem-solving strategies that are creative and collaborative[289].

8.2.3. Different STEM fields may need to be treated differently

Another point of concern is that there is no one-size-fits-all solution, which is especially relevant for the need to consider treating different STEM fields differently, contingent upon the representation of females at the bachelor's degree level[290]. There are the cases of the biological sciences and chemistry, in which the proportion of women at the bachelor's degree level does not lag behind male representation, where the problem is that female numbers can decrease as one moves from education to the workplace. In these fields, the challenge is to sustain STEM interest and intention to pursue a career in STEM. Retention here may primarily depend on factors in the workplace, for instance, implementation of fair employment practices and making use of employment benefits in the frame of family-friendly policies for balancing family life with workplace (parental leave, flexible work times, telecommuting). In other fields, however, where women are underrepresented already at the bachelor's degree level (e.g., engineering, physics, CS)[291,292], the relative proportion of females improves along the pipeline. The challenge in this case is to recruit women at an early stage to enter STEM fields, which strongly depends on self-efficacy, perception of fitting in the field, and outreach initiatives for middle school students, such as summer camps and extracurricular programs.

8.3. Problematize the "leaky pipeline" metaphor

Critical readings of the "leaky pipeline" metaphor and its assumptions for linearity and unidirectionality in people's career trajectories criticize (1) the normative paradigm of a supposedly deterministic series of subsequent stages that women have to follow; (2) its overt focus in the supply-side (i.e., what is currently offered within a largely masculine culture), and not the demand-side (i.e., women's needs and desires), which may be equally important or more important; and (3) the "normalization" of the male condition, according to which the female condition is to be measured and judged[293]. A study reflecting the instrumentality of the "leaky" pipeline metaphor and its inadequacy for grasping a rich account or real-life contexts and the differences between female and male education and employment trajectories focused on undergraduate students in CS in the USA[294]. Females and males displayed different correlational patterns between social support and self-efficacy. For males, decreased self-efficacy was accompanied by decreased social support, reflecting that males with skill deficiency were not sought to provide support nor asked for support from peers. For females, however, there was no straightforward relation between self-efficacy and social support, while a considerable percentage

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work and taking part throughout an entire research process, from outlining a problem to collecting and analysing data; they also provide professional development workshops for graduate school applications and career options.

[289] Jethwani et al. (2017).

[290] Gisler et al. (2018), p. 315-316.

[291] See also Caspi et al. (2019), p. 1191; the study involved 3000 ninth graders in two urban middle schools.

[292] Sax et al. (2017); the study involved data for 8 million students in the USA in 1225 baccalaureate-granting institutions from 1971 to 2011, including 18830 CS majors.

[293] Vitores & Gil-Juárez (2016), p. 5-6.

[294] Rosson et al. (2011); the study involved a survey of 230 undergraduate female and male students enrolled in classes in information science and technology at a public university in the USA.

(41%) of female students who reported low self-efficacy had strong social support. A possible explanation for the above gender difference could be that self-perception of skill deficiency for females was a driver for actively seeking and finding support. However, an alternative explanation could be that social support for female students was not just contingent upon perceived self-efficacy. In any case, the above findings challenge the instrumentality of the "leaky pipeline" metaphor for women, as well as its projection of male characteristics on female intentions and behaviours. Future research needs to delve deeper into these correlations between parameters, adding a comprehensive qualitative dimension to the massive amount of quantitative data already gathered and analysed.

8.4. Create enabling environments in education and workplace

Despite the fact that most socio-cultural barriers to gender equality in STEM would need generations and wider societal change to be effectively confronted, there are still several initiatives to be taken to combat gender stereotypes and discrimination, starting from today[295]. However, it is always a challenge to deliver adequate incentive structures within the policies planned so as not to address women as a uniform target group, with undifferentiated needs and desires. When discussing and fine-tuning specific policies and their incentive structures to promote gender equality in STEM, policymakers need to consider background socio-cultural conditions, which may create the main tendencies for female STEM attitudes and behaviours, as well as individual female preferences, which may align with socio-cultural norms or not, for instance, in terms of preferable working and labour conditions (i.e., flexible or not) as well as childbearing (i.e., having or wishing to have children or not)[296]. This implies that policies need to apply to the majority of women within societies, but not undermine individual agency and freedom of choice. This latter aspect is most important for policy-making, overall. Adding alternatives to one's range of possible choices is one thing, but dictating one's decisions is another. Educational and policy initiatives and reforms need to create enabling environments, respecting individual choices after the diversity of options and career potential has been well-recognized and respected by all. The major pursuit here should be to remove the barriers skewing female interests, preferences, and choices (gender stereotypes and gender discrimination, including an overlap of biological with social factors, for instance, the overlap of optimal childbearing years with the most productive years in a female's career path) without compromising female agency in making decisions.

8.5. Problematize the role of schools

The role of schools in eliminating the gender gap in STEM, ICT, and CS can be crucial. The directions to be taken, however, do not seem straightforward, in terms of leaving free choice of subjects up to students or sorting and assigning students to curricula[297], and in terms of which benchmarks to mandate so as to monitor female recruitment and retention[298]. The focus in primary schools should be to examine any gender gaps emerging in cognitive abilities in early childhood, at the start of formal schooling[299]. There is the option to underline effort and work instead of innate intelligence or ability, which has been proposed for fostering female interest in STEM for upper primary education[300]. With

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[295] Wang & Degol (2013), p. 328.

[296] Wang & Degol (2013), p. 329.

[297] Pinson et al. (2020).

[298] Casad et al. (2018), p. 781-782.

[299] Wang & Degol (2017), p. 4-5.

[300] Wang & Degol (2017), p. 14.

regard to role models in the primary school, a suggestion is to provide them to students through networking with academic and other partners in local ecosystems and hubs[301]. Networking and acting as a stakeholder can also be beneficial for stimulating and sustaining female interest in STEM in the case of secondary schools, for instance, for informing females about the options they may have for pursuing STEM careers, for reflecting on the social impact of such careers, and for showcasing the potential in STEM careers to work with people, in contrast to an object-oriented representation of STEM careers[302]. An effective transition to these directions for secondary schools will not be easily achieved, however, within the current prevailing exam-oriented culture, which instrumentalises learning in upper secondary education. This decreases learning opportunities for both females and males, on the one hand, and on the other, it pushes back decisive choices of STEM subjects to lower secondary education. This means that students need to decide on their higher education studies based on a limited number of subjects, at a time when they may not have adequate knowledge of and attitudes towards these subjects, leaving much room to socio-cultural factors to determine their decisions, such as gender biases and stereotypes.

8.6. Multi-level approach needed to address the gender gap

The last points concerning secondary schools, as well as most of the main discussion points presented in the previous sections, point towards the need for a multi-level approach in the EU, taken over by stakeholders, to address the gender gap in STEM, ICT, and CS[303]. This should involve planned interventions at: (1) a micro-level, referring to changes in instruction, student-teacher interaction and peer interaction in schools; (2) a meso-level, with educational institutions changing themselves to provide enabling environment's for female students, and targeting positive feedback loops leading to bottleneck effects; and finally, (3) a macro-level, with stakeholders collaborating to collect and analyse cohort data anchored in real-world contexts, allowing for cross-cultural comparisons and for devising and updating a toolkit with concrete tools and methods to combat gender disparities. In this scheme, horizontal initiatives would be needed to screen good practice examples for inter-contextual transfer, while vertical initiatives would be needed to establish a bilateral process of stakeholder communication, maintaining top-down and bottom-up channels for informing policy.

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[301] Wang & Degol (2017), p. 15.

[302] Wand & Degol (2013), p. 328

[303] See Michell et al. (2018).

9. POLICY RECOMMENDATIONS

In accordance with our literature review and analysis, we foresee the following policy actions as the next immediate steps for alleviating gender inequality across the STEM fields and the ICT and CS (including AI and cybersecurity) sector.

9.1. Stakeholder interaction at the EU level (macro-level)

Stakeholder experience of what works in closing the gender gap in STEM should be exploited to devise and update a toolkit for addressing gender disparities. It should include institutional arrangements, provisions for intergroup interaction between stakeholders as well as provisions for ingroup interactions between members and individuals within each stakeholder group. The toolkit needs to be developed and adopted by institutions in administration (Ministries of Education in the EU; competent EU bodies engaged in gender issues and STEM, ICT, and CS; other relevant policy makers), education (nursery and primary schools; secondary schools; higher education institutes; professional organizations and networks of educators) and the workforce (industry partners and their networks). This process should be based on an ongoing stakeholder consultation, engagement, and joint action, and it needs to be designed as a social learning process, involving regular stakeholder meetings for planning, monitoring, and assessing joint action in subsequent iteration cycles. The idea of a European Platform for Gender Equality in STEM, ICT, and CS should be employed and supported by the European Commission to coordinate stakeholder collaboration and social learning in this domain (For the operation of the Platform and the effective implementation of the toolkit, some sort of funding procedure should be foreseen by the EU; this may take the form of a Tender with specific Terms of Reference to be addressed by tenderers, who could undertake the role of the Secretariat of the Platform, see last Section titled "Participatory scenario development and assessment for operationalizing stakeholder joint action in combating gender inequality in STEM, ICT, and CS"). Decision-making heuristics and methods, such as the Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis, as well as participatory scenario development, may be exploited to structure and scaffold this concerted stakeholder interaction.

9.2. Select and analyse cohort data anchored in real-world contexts (macro-level)

Several results of previous research have been reported for convenience samples, while large-scale samples in longitudinal cohorts provide informative but largely decontextualized accounts of female performance and choices. What is missing is a tracking of real-life trajectories through educational levels to career choices and then to employment paths, especially the challenges met and decisions made in transitions between one educational or career stage and the next. What is needed is a set of focused cohorts to monitor participants' paths anchored within concrete, real-world contexts and concentrating on the brute facts they need to face within these contexts. Instead of planning such research as an academic study, stakeholders engaged in gender issues in STEM, ICT, and CS may consider adopting this task by formalizing and aligning their record-keeping and participant input so as to allow for this type of data collection and analysis in a natural manner, namely, as part of their regular record-keeping, monitoring and evaluation procedures. Academic partners may provide scientific and technical support for theoretical backing, data collection and analysis methods; however, data interpretation for policy recommendations needs to be taken up by stakeholders as a joint task.

Cohort data of that kind, supplemented by qualitative input provided by participants at selected points in time, will be a crucial addition to the current databases exploited in the form of She Figures Reports and analogous documentation.

9.3. Create and sustain enabling education and work environments (meso-level)

Education and work environments all over Europe should be asked to make use of the toolkit described in the first section of this chapter and to provide their critical feedback, aiming to offer enabling background conditions for females and males so that the adverse effects of gender bias are minimized and female choices are not compromised by gender bias and stereotypes. The point of configuring and securing enabling institutional environments lies in catalysing institutional change in terms of reconsidering the socio-cultural parameters that have proven indispensable for effectively addressing gender bias and inequality in the long term. Education and work environments must critically reflect on salient and latent social norms with a marked impact on female and male attitudes and behaviours. Any intervention targeting individual attitudes and behaviours should unfold in this direction; harboured within such enabling environments, background conditions for gender equity should be secured, and, at the same time, free choice at the individual level should be respected. It is expected that a combination of adequately co-designed interventions at the individual and socio-cultural levels will be much more successful in combating gender inequality than focusing separately on either the individual or socio-cultural level. Another point to stress is that neither level should gain precedence over the other: An inclusive participatory design with stakeholder involvement needs to address both levels (individual and socio-cultural) at the same time.

9.4. Concentrate on positive feedback loops and bottlenecks (meso-level)

In the former chapters we identified several positive feedback loops for gender inequality, which are cases when the outcome of an event or process (e.g., female underrepresentation in STEM, gender biases, stereotypes, and discrimination) works to positively catalyse this same event or process. Positive feedback loops are especially important for configuring policy, since they describe bottlenecks for gender diversity, namely, instances where the proportion of women is highly likely to decrease. In Table 3, we have summarized these bottlenecks across educational levels and the workplace so that future policy can prioritize these instances. To a great extent, the future research directions we have recommended overlap with these positive feedback loops and bottlenecks. We present a synopsis of the proposed research in Table 4.

Table 3: Positive feedback loops/bottleneck effects for female interest or representation

Educational level/workplace	Positive feedback loops/bottleneck effects
Primary education	○ Female students, already not interested in the educational material they still need to work with, may be further marginalized and discouraged in peer interactions and collaborative work by being trusted less than their male peers. ○ Inconsistency between STEM attitudes/grades and STEM career beliefs for girls, which marks the transition from primary to secondary school, seems to be crucial for consolidating the mindset of female students with regard to field-specific ability beliefs.
Secondary education	○ Fewer numbers of female students interested in STEM careers lead to females being deprived of social belongingness in STEM, which further holds back female STEM interest.
Higher education	○ Solidarity among female academics and researchers may be jeopardized if a certain segment of the female population chooses the path of responsibilisation and another disregards or undervalues this same path. ○ Female students are less likely to persist in initial STEM majors when the introductory STEM course is taught by a female instructor, since female students tend to receive lower grades in courses taught by female instructors.
Workplace	○ The declining percentage of females at higher positions has an adverse effect on female recruitment, which decreases further the odds of females being appointed to higher positions. ○ The social media ad market prizes female "eyeballs" due to increased likelihood of conversion, which results in a lump sum invested in an ad reaching more men than women.

Note: A positive feedback loop describes the situation when the outcome of a process enhances that same process in the next round of events, and, thereby, results in an increase in that same outcome; the term "bottleneck effect" refers to a drastic decrease in a reference population, which is most often accompanied by a relative decrease in the diversity within this population.

Table 4: Recommendations for future research on gender inequality and discrimination in STEM, ICT, and CS

Educational level/workplace	Recommendations for future research topics
Primary education	○ Gender differences in trusting female and male peers and teachers; determinants of trust ○ Inconsistency between attitudes/grades and career beliefs among female students
Secondary education	○ Initial interest in and female persistence in educational fields and career paths ○ Determinants of choice of subjects by females and males in racial/ethnic minorities ○ Effect on performance and self-concept of currently used learning approaches or strategies, such as (1) inquiry-based learning, (2) nature-of-science approaches, (3) open schooling, (4) citizen science, (5) peer assessment and the (6) jigsaw approach

Educational level/workplace	Recommendations for future research topics
Higher education	○ Responsibilisation in female academics and researchers' consideration of their cultures and practices ○ Gender of instructor in introductory courses and persistence in the relevant majors ○ Effect on performance and self-concept of currently used learning approaches or strategies, such as (1) inquiry-based learning and (2) peer assessment
Employment	○ Examining the potential of flextime and telecommuting to further assist women in restoring their career trajectories and choices after giving birth ○ Gender differences in the delivery of social media ads for STEM careers ○ Identifying and eliminating discriminatory algorithms to ensure non-discrimination in Artificial Intelligence ○ Determining the critical mass of women for decision-making bodies and board composition needed to yield higher firm performance

9.5. Problematize reference material and pedagogical approaches (micro-level)

The reference material used across all educational levels, textbooks, pedagogical content knowledge, pedagogical scenarios and instructional practice, all need to be problematized so as to identify existing gender bias and gender stereotypes in content, as well as in teacher-student interactions, which may hinder gender equality. At the same time, it is of paramount importance to select and streamline pedagogical approaches able to promote gender equity. To this end, inquiry-based learning offers a twofold opportunity. First, anticipating a facilitator role for educators is more likely than more rigid instructor roles to accommodate the beneficial characteristics to sustain female interest in STEM, such as rapport, on the one hand, and stimulating female empowerment and self-regulation in learning, on the other. Second, inquiry-based learning often builds on a critical mindset for the reference material to be used by students, challenging existing knowledge types and data sources, and promoting comparison and triangulation, which is highly likely to problematize content still contaminated by gender bias and stereotypes. Combining inquiry-based learning with nature-of-science approaches and socio-scientific issues[304,305], which present a relatively increased demand for verbal ability and skills compared to other approaches in STEM, is also expected to prove instrumental for sustaining the interest of females in STEM, for whom it is necessary to jointly target math and verbal ability and skills (see "Secondary education", "Achievement and attitudes": since female students tend to excel in both math and verbal skills, while males perform well in math only, females can choose subjects from a broader range of available option than males, which renders them less likely than males to choose STEM, ICT and CS; at the same time, the above effects imply that educational interventions focusing on

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[304] Hovardas & Korfiatis (2011).

[305] Hovardas (2013).

both math and verbal skills may be more instrumental for sustaining female interest in STEM, ICT and CS).

9.6. Problematize peer interactions (micro-level)

Pedagogical scenarios designed to augment the impact of collaborative learning, such as the jigsaw approach and peer assessment, are expected to expose female students to a representative overview of peer attitudes, with beneficial effects in terms of descriptive norms (what peers usually think or do in a particular circumstance) and injunctive norms (what peers should think or do in a particular circumstance, indicating approved and disapproved behaviours). The jigsaw approach involves students switching from an initial peer group, to which they are assigned in order to accomplish a main task, to an expert peer group, where students specialize in learning to perform specific sub-tasks that are crucial for the effective completion of the main task. When students return back to their initial group (called the "home" group), they need to contribute their specific expertise and collaborate with their peers to complete the main task. Although the jigsaw approach is expected to reveal the heterogeneity in peer performance and attitudes, helping females identify other females with STEM interest, for instance, it needs to be backed up with a training session to empower students so that they can teach one another about specific sub-tasks[306,307]. A similarly demanding approach in terms of training, but one that is also empowering for students, is a reciprocal peer assessment arrangement, where students undertake learning tasks to create learning products and then take over the assessment of peer artefacts by providing peer feedback[308]. In combination with the anonymity options provided by computer-supported learning environments, peer assessment can offer multiple opportunities to female students not only for receiving but also for providing peer support, without being restricted by gender bias and discrimination.

9.7. Participatory scenario development and assessment for operationalizing stakeholder joint action in combating gender inequality in STEM, ICT, and CS (including AI and cybersecurity)

The complexity of determinants of STEM, ICT, and CS (including AI and cybersecurity) performance and attitudes, the fact that their influence may be prolonged and cover many educational levels, in some cases, with delayed effects, the importance of transition periods between educational levels and the move from education to the workplace, and the impact of women's representation in the workplace for choice of STEM subjects during secondary and higher education, point towards the necessity of stakeholder joint action for effectively addressing gender inequality. In contrast to the sporadic and fragmentary interventions that may be undertaken by individual females themselves, their schools, or policymakers at different scales, an institution that would restore continuity in stakeholder interaction and initiatives is urgently needed at the EU level. A European Platform for Gender Equality in STEM, ICT, and CS, with representative stakeholder membership from all competent partners across Europe, chaired by an EU body and supported by a Secretariat, could be the institutional frame for coordinating stakeholder joint action. The Platform could undertake action horizontally, for comparing between different contexts at the same level of reference (e.g., cross-national comparison of secondary schools) as well vertically, for establishing and updating a bilateral flow between top-down and bottom-up

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[306] Zacharia et al. (2011); the study involved 38 seventh graders in Cyprus.

[307] Hovardas & Korfiatis (2012); the study involved 71 pre-service teachers in Cyprus.

[308] Hovardas et al. (2014); the study involved 28 seventh graders in Cyprus.

initiatives (e.g., exploiting the experience gained in secondary schools by allowing them propose policy actions based on what works well in terms of minimizing gender inequality).

Table 5 presents draft scenarios developed for joint stakeholder action, with a concentration on focus secondary schools. These can be schools asked or volunteering to take part in initiatives coordinated by the Platform, aiming to test concrete solutions implemented in concrete contexts. The table is based on a multi-level approach, including instruction, student-teacher interaction, and peer interaction at a micro-level (social interactions), the school's culture and role at a meso-level (institutions), and the school's commitment to reform at a macro-level (policymaking). Although we need to underline that the content of Table 5 is indicative only of the multiplicity of options at the disposal of stakeholders, we wish to illustrate a heuristic for progressing beyond the current unsatisfactory condition of gender disparities. Different rows correspond to different levels and topics within each level, while different columns correspond to different scenarios. Business-as-usual scenarios describe the existing state of affairs, small-effort scenarios depict the potential to depart from the current conditions and make a difference, while best-case scenarios describe ideal futures. Depending upon the resources available and stakeholders' ability to mobilize them and profit on them, desirable change towards gender equality can be attempted and assessed. Based on a participatory scenario development and assessment procedure, stakeholders can co-design and put in place many analogous scenarios and detail the concrete steps to materialize them.

The content of Table 5 was based on the premise that special, staged events or procedures to promote gender equality should be avoided, since they may backfire for females and prove detrimental for their self-efficacy, precisely because such staged events are reminders of a supposed or actual female inefficiency or inability. Instead, the rationale of drafted scenarios for focus secondary schools is to fine-tune and adequately adapt their current practice to accommodate the tools and methods promoting gender equality, within a natural course of everyday school practice. For instance, instruction can change by inoculating lesson plans with gender-informed pedagogical approaches, moving beyond the current instruction and curriculum, which are exam-oriented and not questioned in terms of salient or latent gender discrimination. An examples of a new type of instruction to accommodate gender-informed approaches in STEM, ICT, and CS could be inquiry-based learning, with a special emphasis on nature-of-science approaches and socio-scientific issues, which may stimulate both math and verbal skills and which may, thereby, sustain female interest, since females have been reported to score high in both types of skills, as opposed to males, who were found to have less developed verbal skills. The best-case scenario here would be to extend instruction to establish and maintain bridges with external actors, which would further highlight the social impact and implications of STEM, ICT and CS. Specific examples here could be citizen science and open schooling.

Across all cases in Table 5, the most significant step is to plan and implement the small-effort scenario, which will demarcate a kick-off away from the business-as-usual scenario. In this regard, the most important criterion for recruiting focus schools will be their commitment to contributing to reforms (last row of Table 5; macro-level), where schools would be asked to use a toolkit for launching initiatives to confront gender inequality at the individual learner and intuitional levels. The jigsaw approach and peer assessment, which were presented in the previous section, are two pedagogical scenarios, among several others, that concentrate on peer interaction, and that may be included in this toolkit. Focus schools will close the loop in the bilateral, top-down and bottom-up channelling of the flow of information needed for stakeholder interaction to screen good practice for addressing gender inequality. Of course, it will not just be the implementation of the toolkit alone; a whole series of changes are expected in the school's role (i.e., from implementer to stakeholder to innovator) and culture (i.e., from predominantly masculine, to problematized to emancipatory and enabling), which will eventually reflect change in such a school, while all this change will be based on informed instruction (i.e., from exam-oriented to gender-informed to open schooling), student-teacher interaction (i.e., from displaying authority to displaying rapport to inspiring), and peer interaction (i.e., from indifference or competition to collaboration to self-regulation).

Table 5: Draft scenarios developed for joint stakeholder action to promote gender equality in STEM, ICT, and CS: Focus schools in secondary education

	Business-as-usual	Small-effort	Best-case
Peer interaction (micro-level)	Indifference or competition among peers prevailing and setting the agenda	Peers interacting in collaborative learning arrangements with rotation of roles	Interaction between peers capable of self-regulating their learning trajectories
Instruction (micro-level)	Existing curriculum and exam-oriented instruction not questioned	Transition from existing lesson plans to gender-informed pedagogical approaches	Instruction establishing and maintaining bridges with actors external to the school
Student-teacher interaction (micro-level)	Determined by authority and power-differentials between teachers and students	Determined by rapport; teachers in a facilitator role for scaffolding student learning	Teachers inspiring and empowering students as female and male role models
School's culture (meso-level)	Masculine; contaminated by salient and latent gender stereotypes and biases	Problematized, in transition; dominant stereotypes and biases challenged	Emancipatory and enabling for both female and male students and teachers
School's role (meso-level)	Implementer; innovation inhibited/avoided due to constraints, which cannot be overcome	Stakeholder-networked in local ecosystems; constraints addressed by external input	Innovator; using constraints to reconsider and revise existing practices
School's contribution to reform (macro-level)	Top-down policy adapted to local circumstances and implemented with confined flexibility	Using toolkit to launch initiatives at the individual learner and institutional level	Reflecting upon practice to renew the toolkit in regular communication with other stakeholders

1: Draft scenarios are only indicative of possible options to be considered and tested by stakeholders, where concrete steps to materialize each option need to be detailed by stakeholders themselves; transition from business-as-usual to small-effort, as well as transition from small-effort to best-case scenarios, is contingent upon available resources and stakeholder commitment to the social learning process of participatory scenario development and assessment.

2: We refer to the toolkit with concrete tools and methods to combat gender disparities at the individual learner and institutional levels, including pedagogical approaches such as inquiry-based learning, nature-of-science approaches and socio-scientific issues, as well as pedagogical scenarios for catalysing student collaboration, such as the jigsaw approach and peer assessment; see: Chapter "Main discussion points", Section "Multi-level approach needed to address the gender gap"; Chapter "Policy recommendations", Section "Stakeholder interaction at the EU level" & Section "Participatory scenario development and assessment for operationalizing stakeholder joint action in combating gender inequality in STEM, ICT, and CS".

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ANNEX

Annex I: Strengths, Weaknesses, Opportunities and Threats (SWOT) template for gender equality in STEM, ICT, and CS in pre-school and primary education

Strengths (ingroup aspects promoting gender equality in STEM, ICT, and CS)	• Attitudes toward STEM and 21st century skills did not differ between girls and boys. • Ingroup bias with regard to STEM gender stereotypes was reported for girls in early childhood. • STEM interest was negatively correlated for girls with the belief in male suitability for STEM. • Girls had higher average STEM grades than males. • Girls outperformed boys in actual performance on ICT literacy tasks.
Weaknesses (ingroup aspects hindering gender equality in STEM, ICT, and CS)	• Fewer girls than boys were interested in a STEM career at the beginning of high school. • Girls expected to be less successful than boys in STEM related careers.
Opportunities (intergroup aspects promoting gender equality in STEM, ICT, and CS)	• Preference for spatial toys in early childhood was pronounced for females in STEM degrees. • Encouragement and mentoring for achieving gender balance in science needs to start from early childhood. • There are plenty of great female scientists to serve as role models and inspire primary school students. • Role playing in pre-school can be designed/scaffolded to balance professional and family roles. • Pedagogical design in pre-school should aim to broaden the range of gender roles/options deemed eligible. • Early childhood is a crucial period for implementing interventions to enhance female engagement in STEM. • Female self-efficacy for STEM-related professions should be fostered as part of being a "representative girl".
Threats (intergroup aspects hindering gender equality in STEM, ICT, and CS)	• Pre-school boys trusted male characters more, while girls trusted female and male characters equally • Project-based learning in the physical sciences failed to attract female interest in STEM learning.

Note: The template was completed using findings reported in scientific and grey literature reviewed.

Annex II: Strengths, Weaknesses, Opportunities and Threats (SWOT) template for gender equality in STEM, ICT, and CS in secondary education

Strengths (ingroup aspects promoting gender equality in STEM, ICT, and CS)	• Initial interest at the start of high school is crucial for maintaining STEM career interest at the end of high school. • Distancing from traditional gender roles at adolescence favours female STEM achievement, interest and career planning.
Weaknesses (ingroup aspects hindering gender equality in STEM, ICT, and CS)	• Girls have been reported to lag behind boys in math achievement, which had adverse implications for female STEM attitudes. • Although girls tend to perform well in both math and verbal ability, compared to boys who perform well in math only, girls have a broader range of possible options to choose from than males, which results in girls being less prone than boys to make a STEM choice.
Opportunities (intergroup aspects promoting gender equality in STEM, ICT, and CS)	• Having a male teacher who listens to and values student ideas may decrease the odds of females believing than men are better than women in math or science. • Having a supportive network of STEM peers or being exposed to female classmates with a STEM favourite subject had a positive effect on female STEM attitudes.
Threats (intergroup aspects hindering gender equality in STEM, ICT, and CS)	• The stereotypical treatment of female adolescents by males, including teachers and peers as well as parents, has a marked negative effect on female STEM attitudes. • Teacher or parental support may backfire for female self-concept anytime it reminds females of the deficit in interest or ability that was the reason for requesting support in the first place. • Increased female participation in peer groups without a pronounced STEM orientation proved detrimental for female STEM interest due to indirect, implicit mediation by social belongingness. • A preference for STEM or CS by females in racial/ethnic minorities may be instrumental for accumulating social capital (e.g., in accommodating a culture-specific marriage-market incentive structure) and is not always reflected in corresponding subject choices at the university level or in the labour market. • The time frame for consolidating STEM interest for students is confined to lower secondary education, within a period when girls are less likely than boys to maintain STEM interest or maintain a self-concept of computer ability. • Neither restriction of student choices, as in a German reform initiative, nor an increase in the options offered to students, as in a Swedish reform initiative, were enough to accomplish the objective of making the STEM domain more attractive to females.

Note: The template was completed using findings reported in scientific and grey literature reviewed.

Annex III: Strengths, Weaknesses, Opportunities and Threats (SWOT) template for gender equality in STEM, ICT, and CS in higher education

Strengths (ingroup aspects promoting gender equality in STEM, ICT, and CS)	• Natural sciences, mathematics and statistics were the fields with the most women graduating at the doctoral level in 2016 at the EU-28 level. • The ratio of those starting doctoral studies to those having graduated from master's level studies for women was equal to or greater than the one for men in 17 countries for ICT, and in 20 countries for engineering (2016).
Weaknesses (ingroup aspects hindering gender equality in STEM, ICT, and CS)	• Female participation in STEM throughout all levels of tertiary education still lags substantially behind that of males. • CS is marked by female underrepresentation throughout the last four decades, with a salient negative impact on female self-efficacy and interest, an impact that is boosted by the lack of a sense of belongingness. • Female students in higher education in Europe and elsewhere displayed lower levels in perception of their own abilities. • Females attributed responsibility and blame to themselves anytime they were not able to engage in activities to the same extent as their male colleagues, which needs to be framed within a broader "responsibilisation" culture permeating academia.
Opportunities (intergroup aspects promoting gender equality in STEM, ICT, and CS)	• Concerning peer interaction in student groups, a crucial parameter seems to be the time allowed to females for talking with peers, where the opportunity for equal participation in collaborative work seems to foster female confidence.
Threats (intergroup aspects hindering gender equality in STEM, ICT, and CS)	• An issue of concern is whether the dominant, masculine cultures in higher education institutions are reproduced by means of bias intervening in search committees and hiring decisions. • Available evidence shows that the gender productivity gap in highly cited journals, which disfavours females, increases with productivity, and may be better explained by gender discrimination than gender differences in abilities or choices. A striking finding was that a substantial majority of undergraduate women enrolled in biology courses at a public university in the USA (70.5%) acknowledged having experienced sexual harassment from their instructors in the previous year. • Female persistence in STEM majors dropped when the introductory STEM course was taught by a female instructor, which may be attributed to female students receiving lower grades in courses taught by female instructors, leading to relatively decreased persistence. • Increased contact with advisors and participation in study groups was negatively linked to timely degree completion in STEM for female students, which may be attributed to the fact that support-seeking may backfire for STEM self-concept.

Note: The template was completed using findings reported in the scientific and grey literature reviewed.

Annex IV: Strengths, Weaknesses, Opportunities and Threats (SWOT) template for gender equality in STEM, ICT, and CS in employment

Strengths (ingroup aspects promoting gender equality in STEM, ICT, and CS)	• Although women employed as scientists and engineers in the EU-28 (40.8%) remain fewer than men, there was a mean annual increase in the female proportion of 2.9% between 2013 and 2017, with the growth rate for women being higher than that for men. • In knowledge-intensive activities, there is a much higher proportion of women (around 44%) than of men (around 29%).
Weaknesses (ingroup aspects hindering gender equality in STEM, ICT, and CS)	• The percentage of women in ICT careers still remains relatively low, and it is currently below 2% of the women's total share in the European labour market. • Recent research in the USA documented that women holding a degree in CS or engineering were not as likely as their male colleague to persist in the workplace.
Opportunities (intergroup aspects promoting gender equality in STEM, ICT, and CS)	• Female respondents could be as motivated as male respondents for engaging in STEM, if not discouraged by gender bias. • Increasing female representation in teams enhanced team identification for female team members, facilitating their psychological attachment to and confidence in the team, and further, fostering collective efficacy and team performance. • Gender diversity was found to favour the potential for innovation for technological companies. • With regard to decision-making bodies and board composition, board gender diversity yielded higher firm performance when there was a critical mass of women on the board. • At the EU level, gender equality is expected to have a series of positive impacts on the GDP of the EU, the competitiveness and balance of trade of the EU economy, and job supply. • Comparing institutions established to close the gender gap in the USA and Europe, the repertoire of institutions in the USA is richer and involves engaging women at the individual level of reference, mentoring, and gender equality in the workforce. • In contrast to the grassroots origin of most initiatives in the USA, European institutions committed to promoting gender equality are more stakeholder-based and organized as networks of actors in a top-down fashion, lacking vertical connections to local contexts.
Threats (intergroup aspects hindering gender equality in STEM, ICT, and CS)	• Two major aspects reflecting gender discrimination are gender gaps in upper-level positions and salaries. • Current institutional arrangements to address family life do not fully compensate for all impact experienced by women. • Gender differences and unintended discrimination were detected in the delivery of social media ads for STEM careers. • Only six EU-15 members and another two EU-13 members have prepared guiding targets for gender balance in decision-making bodies.

Note: The template was completed using findings reported in the scientific and grey literature reviewed.

This study, commissioned by the European Parliament's Policy Department for Citizens' Rights and Constitutional Affairs at the request of the FEMM Committee, provides evidence that there is still gender bias and inequality in STEM (Science, Technology, Engineering, Mathematics) fields and the digital sector (e.g., digital technologies, Computer Science, Information Technology, Information and Communication Technology, Artificial Intelligence, cybersecurity). This document, prepared at the request of the FEMM Committee (Policy Department for Citizens' Rights and Constitutional Affairs, Directorate-General for Internal Policies), is intended to provide an up-to-date literature review on the current status of women's education and employment in STEM fields and the digital sector. In so doing, the corresponding trajectories are examined, from the primary education level up to the employment level, in an attempt to identify obstacles and bottlenecks that prevent gender parity. Finally, suggestions for future research, initiatives and policies that would improve women's participation in these areas are made.

PE 651.042

Print ISBN 978-92-846-6522-8 | doi:10.2861/ 697007 | QA-01-20-241-EN-C
PDF ISBN 978-92-846-6523-5 | doi:10.2861/176275 | QA-01-20-241-EN-N