
WOMEN IN SCIENCE AND ENGINEERING: STUDENTS, PROFESSIONALS AND AUTHORS

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Abstract

In recent years several studies have been published analysing the ratio of male to female authors of published articles in various scientific disciplines over the decades. There is a big difference among disciplines. This paper will present and analyse these differences. There is not only a difference in the total number of papers and articles with women as authors but also whether there are only women authors, women as first or last author, etc. In engineering an important area is also represented by patents. The ratio of men and women in this particular area is much more striking. Looking at academic institutions there are interesting analyses concerning the percentage of full professors. There is a statistically significant decrease in the number of women completing undergraduate study over postgraduate study, and women occupy lower positions in research up to senior researchers or full professors. These numbers vary across continents, with fewer women full professors in the European Union than in the United States. We will present information about the percentage of women researchers in fields related to telemedicine and eHealth, in particular medicine and nursing care in contrast to engineering and medical informatics. The differences are also significant. These numbers correlate to a certain extent with authorship.

Keywords: engineering education; telemedicine; authorship; research; woman researcher; gender.

Introduction

Several studies have recently reported on the proportion of men and women in various scientific disciplines and professions.¹⁻³ They have been followed by discussions in conferences and professional societies. We have decided to investigate this issue in the area of telemedicine and eHealth. Since it is on the border between STEM (science, technology, engineering, and mathematics) and life sciences, we have compared these fields. Telemedicine and eHealth are not followed as separate disciplines in education and jobs, thus are not present in statistics. We have searched for data on education, professions and authorship in STEM and life sciences. For more detailed analysis we have formulated several questions that could help us identify the causes of disproportions in particular in career development. The questions are as follows:

- What are the results in STEM subjects at primary and secondary schools?
- Do we have any explanation of these differences?
- What is the temporal development from university study to senior research position?
- What is the distribution of women and men in various fields?
- Does the ratio in authorship correspond to the number of researchers in the given fields?

Methods

To gain better insight, we first looked at: 1) the information and statistics about primary and secondary education, 2) the distribution of applicants to universities across disciplines, 3) comparison of the ratio of women and men in various jobs, and the issue of vertical segregation, 4) female authorship of journal articles, conference papers, and patents and women's roles as journal Editors, Associate Editors, and Board

Members. The data presented are derived from review of relevant literature.

Results and Discussion

Are there gender gaps in education?

The data presented in this section are based on studies and statistics published by the European Commission,¹ the OECD,² and the American Association of University Women.³ In elementary, middle, and high school in the USA, girls and boys take mathematics and science courses in roughly equal numbers, and about as many girls as boys leave high school prepared to pursue science and engineering majors in college.³ The situation is almost the same in Europe and Asia.^{1,2} However, already at primary schools we can find differences in attitudes, in particular of parents and teachers. These differences are more obvious at secondary schools.

Parents can give their sons and daughters equal support and encouragement for all of their school work and aspirations for their future. The results of the OECD programme for international student assessment (PISA) show that this does not always happen.² In all countries and economies that surveyed the parents of students who sat the PISA test, parents were more likely to expect their sons, rather than their daughters, to work in a science, technology, engineering or mathematics field – even when their 15-year-old boys and girls perform at the same level in mathematics. Teachers can help by becoming more aware of their own gender biases that may affect how they award marks to students.

The analysis of results shows that girls and boys in the top-performing countries achieve comparable scores because they are strongly motivated to be the best. These results strongly suggest that gender gaps in school performance are not determined by innate differences in ability. Although boys are significantly more likely than girls to be less engaged with school and have lower skills and poorer academic achievement, they finally succeed in studying STEM courses. In higher education and beyond, young women are under-represented in the fields of mathematics, physical science and computing. However, when we analyse the statistics in detail we see that the gender gaps in education are widening. Why? The studies have highlighted an interesting finding: there is lack of self-confidence among girls.

In the large majority of countries and economies that participate in PISA, among high-performing students, girls do worse than boys in mathematics and in no country do they outperform boys at this level.² In general, girls have less self-confidence than boys in their ability to solve mathematics or science problems. It is particularly obvious when the students are required to “think like scientists”. In that case girls underperform considerably compared to boys. This gender difference may be related to students’ self-confidence. When students are more self-confident, they give themselves the freedom to fail, to engage in the trial-and-error processes that are fundamental to acquiring knowledge in mathematics and science.²

The OECD study shows interesting variations in differences between boys and girls when solving different types of tasks.² The results are rather worrying. While girls’ lower performance in mathematics and science among the highest-achieving students may reflect lower levels of self-confidence and higher level of anxiety, the differences in levels of self-confidence and anxiety between boys and girls are greater than differences in mathematics and science performance. The study shows results of inquiries among 15-year old boys and girls about careers in computing and engineering on one side and health services on the other side. On average, there are almost four times as many boys as girls who expect to work in engineering and computing. In contrast the proportion of girls planning to work in health services is approximately 9% higher than boys. Another interesting statistic shows expectations of parents about their children’s career. Concerning STEM occupations, there is a significant gender gap. In all countries parents expect that the boys will be more likely than girls to work in STEM occupations (the smallest difference is 7%, the largest is 33%).

A wealth of research has examined how self-beliefs are formed and the key role played by both interpersonal and intrapersonal comparisons.^{2,3} Students’ beliefs about their own competence in mathematics are related to how well they perform compared to their classmates, and also to how well they perform in mathematics compared to their performance in other subjects. Because girls tend to perform so well in reading, they may, unconsciously, believe that they are underperforming in other subjects. As a result, they have less confidence in other subjects, like mathematics, which in turn, could under-

mine their performance. In such situations, the role of teachers and parents is irreplaceable and must be positive and supportive. One way at schools is using cognitive-activation strategies in mathematics.^{2,3}

Women in science and engineering study and jobs

Although the number of women in science and engineering is growing, men continue to outnumber women, especially in higher positions of the professions. Yet fewer women than men pursue the STEM majors. Most people associate science and mathematical fields with “male” and humanities and arts fields with “female”. Implicit bias is common, even among individuals who actively reject these stereotypes. This bias not only affects individuals’ attitudes toward others but may also influence girls’ and women’s likelihood cultivating their own interest in mathematics and science. Not only are people more likely to associate mathematics and science with men than with women, people often hold negative opinions of women in “masculine” positions, like scientists or engineers. Research profiled in the report by Hill et al. shows that people judge women to be less competent than men in “male” jobs unless they are clearly successful in their work.³

The teaching profession up to secondary education is dominated by women. The proportion of women educators declines as the level of education increases and also changes with the taught subject. In STEM courses the share of men is usually higher than in humanities, for example. The proportion of women as teachers in individual levels of education is 97% in early childhood education, 83% in primary education, 68% in lower secondary education, 56% in upper secondary education, and 41% at the tertiary level.²

In the European Union, the share of women in total employment reached 45% in 2010, but women made up 53% of tertiary educated people who were employed as professionals or technicians. However, only 32% of scientists and engineers were women. Although the proportion of female researchers has been growing, the gender imbalance in the research population increases with age.^{1,10}

When looking at American statistics we can see that at high schools the girls earned more credits in mathematics and science than boys (the study presented data from 1990 till 2005).³ In evaluation of grade point average this difference is even more obvious. Although results of girls at high schools are

encouraging, when entering college and later university the ratio changes, in some fields rather dramatically. Statistics of 2006 show that 29% of all male freshmen (1st year students), compared with only 15 percent of all female freshmen, planned to major in a STEM field. The gender disparity in plans to major is even more significant when the biological sciences are not included. More than 20% of male students planned to major in engineering, computer science, or the physical sciences, compared with only about 5% of females.³

Despite the still relatively small percentages of women majoring in some STEM fields, the overall proportion of STEM bachelor’s degrees awarded to women has increased dramatically during the past four decades, although women’s representation varies by field. In 2006, women earned the majority of bachelor’s degrees in biology, one-half of bachelor’s degrees in chemistry, and nearly one-half in mathematics. Women earned a much smaller proportion of bachelor’s degrees in physics, engineering, and computer science. The report shows statistics over 40 years (1966 – 2006). In biology, chemistry, physics and engineering the percentage of women bachelor’s degrees were growing, but were decreasing slightly in mathematics. The decline in computer science, from a peak of 36% in 1986 to only 20% in 2006, is significant.³

Of course, the absolute numbers vary across disciplines. We present numbers of graduates from the year 2007 in several disciplines that are close to telemedicine and eHealth: biology, 48,001 women and 31,347 men; computer science, 7,944 women and 34,652 men; and electrical engineering, 2,109 women and 16,438 men.³

Doctoral degree recipients

Women’s representation among doctoral degree recipients in STEM fields also has improved in the last 40 years. The most impressive increase is in biology from 12% to 47%. However, even in computer science, engineering and physics the percentage improved from 0 or nearly 0, to almost 20 percent. These numbers are very similar both for Europe and the United States.^{1,2}

The changes in STEM professions almost copy the changes in STEM degree recipients. In almost all areas there has been continuous increase from 1960 to 2000. Only in mathematics and computer science has there been a drop of 5% between 1990 and 2000 (from 35%

to 30%). Among workers who hold doctorates, men represent a clear majority in all STEM fields. In the academic workforce, women's representation varies by discipline as well as tenure status. In 2005, 40% of full-time faculty in degree-granting colleges and universities in the U.S. were women.

However, women's representation in STEM disciplines was statistically significantly lower. Women made up less than one-quarter of the faculty in computer and information sciences (22%), mathematics (19%), the physical sciences (18%) and engineering (12%). In the life sciences, an area in which many people assume that women have achieved parity, women made up only 34% of the faculty. In all cases women were better represented in lower faculty ranks than in higher ranks among STEM faculty in four-year colleges and universities.^{1,3} In Europe the proportion of women among full professors is highest in the humanities and the social sciences, 28.4% and 19.4%, respectively and lowest in engineering and technology at 7.9%. These numbers lead to discussion on horizontal and vertical segregation.¹

Horizontal and vertical segregation are terms expressing differences in representation of females and males in disciplines and in hierarchy. Horizontal segregation means different representation of men and women in individual disciplines and sectors. Women are more frequently active in the so-called soft disciplines (humanities and social sciences) and employed mostly in governmental (37%) and non-profit (38%) sectors. In the entrepreneurial sector there are only 15% of females in research and development. There is great contrast between soft disciplines (43% of female researchers) and engineering (12% of female researchers).¹

Vertical segregation expresses concentration of men and women on different levels of academic hierarchy. Women are more frequently represented on lower positions in the hierarchy, while men have the majority on decision making positions. The situation is almost the same across disciplines and sectors. In 2010, on average throughout the EU-27, 15.5% of institutions in the Higher Education Sector were headed by women, and only 10% of universities had a female rector.¹

We can confirm this distribution by numbers from the universities in the Czech Republic: among 25 rectors of public universities, only 2 are women. Of the 62 directors of research institutes of the Academy of Sciences, 12 are female. A similar situation exists in

other sectors.⁴ Women represent 56% percent of all university educated graduates in the Czech Republic and about 43% of PhD graduates. However, in jobs the ratio changes, in particular in higher positions. When we observe the numbers in research and development, females constitute only 26%.⁴ They are concentrated in specific scientific areas and in lower positions in the hierarchy. Definitely one of the reasons for this is care for children and family. If a woman does not find support in her family, it is usually difficult to continue the career, in particular in areas where for example, frequent and whole-day presence in laboratories is required. These facts show that without systematic work and support from the side of the institutions it is almost impossible to reach more satisfactory results. These observations were also confirmed by the study performed by Servou and Visser.¹⁰

Hewlett et al. focused their study on numbers in business and reasons why women quit engineering jobs.⁵ On the lower rungs of corporate career ladders, fully 41% of highly qualified scientists, engineers, and technologists are women. But the dropout rates were huge, and over time 52% of these talented women quit their jobs. What were the reasons? The authors identified 5 serious aspects. First and foremost, the hostility of the workplace culture drives women out. Second, is the dispiriting sense of isolation that comes when a woman is the only female on her team or at her rank. Third, there is a strong disconnect between women's preferred work rhythms and the risky "diving catch" and "fire-fighting" behaviour that is recognized and rewarded in these male-dominated fields. Fourth, "extreme jobs", with their long workweeks and punishing travel schedules, are particularly prevalent in science, engineering, and technology companies. Fifth, many women surveyed bemoaned the "mystery" around career advancement.

Although the statistics do not follow jobs in telemedicine and eHealth separately, we can derive the ratio from the numbers in STEM and medicine jobs, where engineering and information technology are in the majority. That means that in the technical positions men dominate while on the other hand women dominate in care positions.

Authorship – ratio of women and men

Several studies on the role of gender in scholarly authorship have recently been published.^{6,7,8} The statistics on authorship and proportion between women and men are correlated with the numbers of

women and men working in scientific disciplines (STEM vs. humanities and life sciences). Men publish more papers on average than women, although the gap differs between fields and subfields. Women publish significantly fewer papers in areas in which research is expensive, possibly as a result of policies and procedures relating to funding allocations.⁶

Lariviere et al. present a global and cross-disciplinary bibliometric analysis of:

- The relationship between gender and research output (authorship)
- The extent of collaboration (co-authorship)
- Scientific impact of all articles published between 2008 – 2012 and indexed in the Thomson Reuters Web of Science databases (citations).

They analysed 5,483,841 research papers and review articles with 27,329,915 authorships.⁶ Their findings are interesting but unfortunately not very surprising. All articles with women in dominant author positions receive fewer citations than those with men in the same positions. Men dominate scientific production in nearly every country. Globally, women account for fewer than 30% of fractionalised authorships. Women are similarly underrepresented when it comes to first authorship. For every article with a female first author, there are nearly two (1.93) articles first-authored by men. South American and Eastern European countries demonstrate greater gender parity.⁶

Specialties dominated by women include nursing; midwifery; speech, language and hearing; education; social work; and librarianship. Male-dominated disciplines include military sciences, engineering, robotics, aeronautics and astronautics, high-energy physics, mathematics, computer science, philosophy and economics. Although disciplines from the social sciences show a larger proportion of female authors, the humanities are still heavily dominated by men. Another key limitation is that authorship of papers is only one of many indicators of research activity. Moreover, the analysis was only of journal articles and books and conference papers were not considered.

West et al. performed another study using a different source of documents for analysis. They focused on the authorship order, given that first and sometimes last author publications are at least as important as raw publication counts for hiring, promotion, and tenure, particularly in scientific fields.

The study used the JSTOR corpus, comprising more than 8.3 million documents from 1545 to 2011, including 4.2 million research articles. Overall, 21.9 % of authors were female irrespective of their position in the list of authors. The ratio is very different in various disciplines; mathematics 10.6%, law 24.2%, cognitive science 32.1% and education 46.4% (data were taken from 1990 till 2011).⁷

Studies of authorship in the medical literature reveal that women have been historically underrepresented in the prestige positions of first and last author, although the ratio of women and men is almost balanced.⁷ As already mentioned, telemedicine brings certain technical issues to medicine, thus the number of men as authors is higher than women. There are differences connected with the content of papers. Papers focused on aspects of care have more women as authors. Technical articles have more (or only) men as authors. Since telemedicine and eHealth are still relatively young disciplines it is too early to make any conclusion about the temporal development of balance between female and male authorship. It will definitely be closely correlated with ratio of women in STEM jobs, since in medicine the numbers are almost balanced.

Vela et al. analysed publications in software engineering in terms of gender. This was an empirical study of female participation in 12 leading software engineering journals over a two year period. The main goal of the study was to analyse the participation rate of women as authors and whether women are underrepresented on editorial boards and as editors-in-chief by taking as the reference population the number of authors of the journals selected to discover whether there is a glass ceiling for women in this area of computer science.⁸ The absolute numbers considered in the study were 3,546 authors of 1,266 papers from 61 different countries, and 363 members of editorial boards from 30 different countries.

Women appear as the first author in 17.4% of all the papers considered. The US was the most productive country with 954 authors which corresponds to 27% of all authors. Female authors from the US comprise 17.9% of US authors which is close to world average. The female author ratio from several European countries varies from highs of Finland 34.4%, Spain 33.9%, and France 23.4% to less than 10% from Ireland, Austria, Belgium, Netherlands, Germany and Greece. Not all EU countries were included in the analysis due to missing data. The

imbalance in editorial boards is more marked. Of the 12 journals, males dominate as Editors-in-Chief (90.5%), Associate Editors (76.1%), and Editorial Board Members (82.1%).⁸

Hunt et al. performed an analysis of patent authorship. The gender gap in patenting rates is much more pronounced than the gender gap in many other endeavours: American women patent at only 8% of the male rate. The highest shares were for Spain and France (12.3% and 10.2% respectively), while the lowest shares were for Austria and Germany (3.2% and 4.7% respectively). The authors analysed the reasons and found the following gaps in field of study, degree, number of commercialised patents, and in job positions. All of them have as a cause the underrepresentation of women in electrical and mechanical engineering which are the disciplines with the highest number of patents.⁹

Conclusions

The striking disparity between the numbers of men and women in science, technology, engineering, and mathematics has often been considered as evidence of biologically driven gender differences in abilities and interests. The classical formulation of this idea is that men “naturally” excel in mathematically demanding disciplines, whereas women “naturally” excel in fields using language skills. Recent gains in girls’ mathematical achievements demonstrate the importance of culture and learning environments in the cultivation of abilities and interests. However there are many stereotypes found in children’s books, school manuals, gendered attitudes of teachers, gendered advice, and guidance on courses to be followed. A concerted effort by parents, teachers, policy makers and opinion leaders is needed if boys and girls are to be able to realise their full potential and contribute to the economic growth and wellbeing of their societies. Finally we should mention that there are also areas where men are underrepresented. We presented the percentage of teachers at all levels of education from which it follows that in particular at primary and secondary schools the male element is missing. There were few studies performed that analysed the reasons. Similar underrepresentation of men is in health care, social care and humanities. If we want to study the gendered pattern of study and job choice, it is necessary to consider both sexes equally.

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