

Investigation into the Past and Future of Women in Science and Engineering

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Abstract— Covering the Ancient Greek era, the Middle Ages, the Renaissance, the Enlightenment, the 19th and 20th C., this paper explores the visions of the abilities of women, their access to education, and their roles in these epochs. Recent data on the participation rate of women in science and engineering, the culture in these fields, and strategies to increase their presence are discussed. The paper ends with a discussion on how science and engineering could benefit from integrating and valuing a blend of masculine and feminine perspectives. Biomedical engineering as a field frequently chosen by women is mentioned.

I. INTRODUCTION

In my work as holder of the Northern Telecom/NSERC (Natural Sciences and Engineering Research Council) Chair at the University of New Brunswick, December 1989 to June 1997, my mandate was to encourage an increased participation of women in engineering in Canada, working with universities, employers, and the profession to develop women-friendly policies. The Chair tasks also included teaching and research in electrical and biomedical engineering. In 1997, I was appointed Chair for women in science and engineering in Ontario, and engineering professor at Carleton University and the University of Ottawa. Thirteen years spent in these various roles enabled me to discover many of the important issues limiting women's participation and to recommend solutions. [1]

To understand why many girls and women still shy away from science, mathematics, engineering, and technology, it is helpful to examine the educational opportunities for girls and women, compared to that of boys and men, and how society viewed women's intellectual abilities in past eras. We also need to look at how the culture in science and engineering developed, and discuss how it can be an obstacle to women's full participation. Biases and double standards that favor men for awards, prizes, fellowships, and positions still exist as demonstrated by Wenneras and Wold [2] and Sonnert and Holton [3] and others.

There have been brilliant women seriously involved in many fields of knowledge since the beginning of recorded history, but it is only recently that their lives and work have come to light. To date, history was his story and few women appear in mainstream historical accounts of science and technology. An example is Margaret Alic's *Hypatia's*

Heritage [4] which provides a history of women in science from Antiquity to the 19th C., in Alexandria, Greece, and Europe. It is encouraging to find that the obscurity in which women remained for so long is finally lifting. Schiebinger [5] and Fox-Keller [6] discuss obstacles to women's participation in science and provide examples on how a feminine approach in certain fields like primatology and archeology led to corrections of some previously incorrect interpretations in these sciences. Examples can be found in the work of Jane Goodall and Dian Fossey, who used a different approach to the study of chimpanzees and gorillas, adding new information to previous studies, even contradicting some notions regarding the behavior of females. Many other examples can be found in the literature. (See references 5 and 6 among others).

Views on women's intellectual abilities and education

In Ancient Greece, Plato (429-347 BCE) [7] envisioned that women and men with talent should have access to the same education and public roles; one's biology, i.e. women's childbearing capacity does not carry with it the obligation to take care of children, and men's lack of it, the incapacity to take care of them. The resistance to women's equality is not due to the absence of rational arguments. Plato's argument is that equality, or inequality is related to ability, capacity, and potential and thus supports the idea of allowing certain women to participate equally in society. This is based on the principle that one ought to hold an occupation according to one's ability; and since some women share the same abilities as some men, they should be provided the same opportunities. The deeper principle is: A society's structure ought to be based on what is natural; this is why Plato charged his Athenian society with unnaturalness, as it denied women access to education.

Plato's student, Aristotle (384-322 BC), thought that "the male is by nature fitter for command than the female, just as the elder and full-grown is superior to the younger and more immature". [8] While Plato thought that women shared the same capacities or virtues as men, Aristotle saw such virtues as different so that "the courage and justice of a man and of a woman, are not the same; the courage of a man is shown in commanding, of a woman in obeying." [8] In several texts, Aristotle claims that women are inferior to men and argues that "the female is as it were a deformed male". [8]

The Plato-Aristotle debate was repeated throughout the ages in various forms. Today, when we think of science, we usually think of it as separate from, and sometimes even

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antithetical to religion. But in the medieval period, science was part of natural philosophy. It was not until the 17th C. that science began to occupy a separate niche and develop distinct methods of inquiry; but even then, it was still very much mixed with theology, alchemy, and magic. Noble (1993) suggests that the medical and scientific ideas of the ancient world were appropriated into the misogyny of the religious medieval world. [9] Writers appealed to religion to justify or re-affirm social structures in which women had few rights. In each era, there have been thinkers who supported access to education and to public roles for women and others who entrenched the patriarchal views of Aristotle. In the medieval period we find Averroes in the former group, and Augustine, Avicenna, and Aquinas in the latter. It was Aquinas' ideas about women that were to win over Averroes'; in effect, Aristotle's over Plato's. And it was the mechanistic and dualistic science of Bacon and others in the 17th C. that won over the hermetic tradition of Paracelsus. Aristotle's and Aquinas' views helped perpetuate views that were already patriarchal in form and well entrenched. Plato, Averroes, and Paracelsus offered alternatives, but they were small voices in a large crowd.

In the 17th C., the majority continued to portray a negative view of women's abilities, thus continuing to severely limit their access to education. A few exceptional men and women in the Renaissance and Early Modern Europe (15th to 17th C.) argued in favor of women's abilities and the provision of universal access to education. Marie le Jars de Gournay (c1565-1645), born in Paris, quickly understood that the only education possible for women at the time was self-learning; so she taught herself languages and learned Latin by comparing French translations with original Latin texts. In addition to her prefaces to Montaigne's work, she published two treatises: *Egalité des hommes et des femmes* (1622) and *Grief des dames* (1595). In this period, there were many advances in science, but most historians profile only the men (Copernicus, Brahe, Kepler, Descartes, and Newton). They rarely mention Hildegard von Bingen, who wrote about heliocentricity 400 years before Copernicus, or Sophia Brahe, who made discoveries and measurements in astronomy with her brother Tycho. Surprisingly, 14 % of astronomers in Germany in the 17th C. were women! [5]

Noble traces the historical origins of modern scientific culture by studying the professional societies, the academies, and universities. [9] He argues that a world without women did not simply emerge; it was constructed. An important factor was the rise of clerical asceticism in the 2nd C., upholding patriarchal patterns of female subordination and the exclusion of women from education. At the end of the twelfth Century, the first western universities appeared in Paris, Oxford, and Bologna, arising from ecclesiastical schools; they were exclusively for males, establishing a masculine culture in science and learning that has lasted for centuries.

In the Middle Ages, women became involved in alchemy, herbal medicine, and midwifery, leading to a witch-hunt that began by a papal bull in 1484 (Innocent VIII), particularly intense in the 16th and 17th C. in France,

Italy, England, and Germany. In James I's *Daemonologie* (1597), some hundred thousand persons were tried, eighty-three percent of them women, primarily persons from the lowest classes, even though the beliefs for which they were tried were popular at all levels of society. Religious, social, and sexual attitudes toward women and their role in contemporary society played a significant part in delineating the victims. [9] The feminization of witchcraft, while connecting magic, malfeasance, and heresy to it, provided the momentum to remove women from the roles they played in these fields. Male physicians played a prominent role in the witchcraft persecutions, perhaps to eliminate competition from lay healers and midwives. The revivalist spirit of Reformation rekindled asceticism, and the Royal Society, founded in London in 1662, distanced itself from anything feminine, as this could be associated with witchcraft and alchemy. The Royal Society instituted the clerical and academic, hence male monopoly, over natural philosophy.

In the Renaissance period, earth and nature had been portrayed as a nurturing mother. In the 17th C., the image became that of a disordered female demanding mastery. Francis Bacon (1561-1626) advocated using the new experimental philosophy to inaugurate the 'truly masculine birth of time', to lead men to 'Nature' with all her children, to bind her to your service and make her your slave,...to conquer and subdue her, to shake her to her foundations. Bacon urged researchers to use his method to discover the 'secrets still locked in Nature's bosom',...to penetrate further,...to find a way into her inner chambers,...to storm and occupy her castles and strongholds, and extend the bounds of human empire. [10] These metaphors clearly express control of Man over Woman, and of Man over Nature; it unequivocally portrays a masculine philosophy of science that would not appeal to many women. Early industrial capitalism of the 17th and 18th C moved production from the home to the workshop, so women lost their independent wage earning opportunities and reduced to the state of dependent housewives. Even in the 20th C. we find metaphors and language that objectified women. Richard Feynman, in his 1965 Nobel address, spoke of scientific theory as a beautiful young woman to be wooed and won; as the theory aged, it remained to be honored merely as an old mother who has produced children. Paul Feyerabend saw nature as the compliant mistress whose sole function is pleasuring the (male) scientist. [11]

In spite of many obstacles, women found various ways to be involved in science in the 17th and 18th centuries. Some started Salons where literary and scientific discussions were held and experiments were performed. In the Midlands, women participated in discussions with members of the Lunar Society; they went on geological explorations, down caves, and studied plants. Women wrote on mathematics and science. Notable examples are Mary Fairfax Somerville (1780-1872) and Gabrielle-Émilie de Breteuil, Marquise du Châtelet (1706-1749).

During the Enlightenment, a dark voice against education for women was Father Nicolas Malebranche (1638-1715), a French priest and Cartesian philosopher, who endorsed the

belief that men were superior to women, invoking nature and women's anatomy to describe the inadequacy of the female mind. Malebranche's superficial assessment of women's abilities did not consider the constraints placed on them at the time. [12] For his part, François Poullain de la Barre (1647-1723) argued that the intellectual capabilities in men and women are equal, using Descartes' separation of the mind from the body and mixed his views with religion as Aquinas did. According to him, and in keeping with John Stuart Mill's views, those who think women inherently inferior have confused a woman's nature with a woman's upbringing and the society she lives in. Although the mind has no sex, a person who is in a different societal role by custom will appear to have a different nature. Poullain combined the Cartesian idea of a sexless mind with an analysis of society and custom, in order to argue for women's *equal nature*.

But the enormous influence of Jean-Jacques Rousseau made the situation worse for women in the 18th C. than it had been in the 17th C. For Rousseau, women's end is to be agreeable to man... and one wastes time trying to explain to women the reasons behind ideas such as religious beliefs. Women should simply follow men's directions. He speaks vehemently against making the two sexes the same as this would lead to 'intolerable abuse'. [13] In his view, if women were educated like men, they would stop controlling men by their charm, femininity and dependence. He maintained that a woman was worth more as a woman than as a man. [13] For one hundred years, writers supported Rousseau's arguments for a different education of girls and boys.

Prior to universities opening their doors to women in the late 19th C., the education of girls was mostly done at home and linked to future household duties; boys learned Latin, Greek, and the Classics. An interesting development occurred in the 17th C., where private schools for girls began to teach languages, mathematics, herbal medicine, and science (astronomy, botany). Bathsua Makin (c.1600-1676) championed education for girls through *An Essay to Revive the Antient Education of Gentlewomen* and opened her own school for girls in 1673; she was known as the most educated woman in England. Another champion was Comenius who favored the public education of girls and boys in his treatise on school reforms in England in the 17th C. Anna Maria von Shurmann and Mary Astell were other supporters of education of girls. Some girls' schools taught science and mathematics between 1660 and 1860, while boys concentrated on the Classics, Greek and Latin, topics valued by gentlemen at the time. But in 1860, major school reforms occurred in England where girls were now to learn Latin and the Classics, to prepare for entrance in university, which finally opened their doors to them; boys began to be taught science and mathematics, subjects neglected to date in boys' schools. Emily Davies, who provided the first access to a university education for women in England faced many challenges and obstacles. Unfortunately, she insisted that girls learn what the boys had been learning in the past, not their new curriculum. This pattern remains to this day. [12]

A frequently heard statement is that biases and prejudices on women's abilities and skills are a thing of the past. But the debate is still alive. The question is not related to epochs, with the assumption that time will fix things. Progress is cyclical, with times of positive change, followed by periods of regress, sometimes with backlash. The march toward equality has not been constant. There is evidence that women's full and equal participation in society is neither a result of the passage of time, nor guaranteed. Examples of bias in contemporary times have been documented, as mentioned in the introduction [2, 3].

It is important to examine the culture in science and technology and its potential impact on the participation of women. For example, who does science; what are the attributes and characteristics of its workers, and which ones are valued and respected? Language and metaphors, research topics that get funded, published, and rewarded are key drivers of modern science. Sorensen et al. studied the culture of engineering; they wrote: "[T]echnology is decisively shaped by social relations, i.e. the political and economical needs of managers in industry or by military interests." [14] This study inferred that technology is characterized by masculinity and influenced by masculine interests. This results in a male dominance in engineering and computer science, especially in the high-technology sector, as described by Robinson and McIlwee. [15] Exceptions are the fields of biomedical, chemical, and environmental engineering, where women make up close to half of the students in these programs. According to the American Society for Engineering Education, women earn a greater percentage of degrees in Biomedical Engineering than in any other engineering discipline. One reason for this seems to be the social relevance of work in this field, such as developing tools and approaches to aid in diagnosis, therapy or monitoring and improving health care. In 2000, 39 percent of degrees in biomedical engineering were awarded to women, 34 percent at the Master's level, and 32 percent at the doctoral level. In the same year, the proportion of degrees awarded to women in all fields of engineering was low compared to the biomedical field: 20.5 percent at the Bachelor level, 20.7 percent at the Master's level, and 4.6 percent at the doctoral level. [16] Progress on hiring women faculty and appointing women as administrators is very slow.

Although recent studies show that girls do as well as boys in science and mathematics, most girls do not consider science or engineering as a career. Outreach programs need to be tuned to the teen culture of the time and reach adults who may influence the teens. Ensuring course choices are a good fit with the students' interests and abilities and providing networking opportunities for students in lower years to meet older students are key strategies for retention. Long-term structural and cultural changes are essential to make engineering programs more hospitable to female students. While the environment and the student newspapers have improved, demeaning jokes or comments are still made from time to time by students and professors and inappropriate articles and images occasionally reappear. A boot-camp mentality is still displayed during frosh week at

some institutions. Suggestions to improve the climate for women are: Using gender-inclusive language; connecting the theory to socially relevant applications; setting-up work groups so that a critical mass of women are included, even if some groups end up having men only. Retaining more women students will bring a positive change to the culture and make the environment friendlier for all. Attracting more women into graduate programs and hiring more women faculty will also have a positive impact. Moody [17] presents some of the frequent myths and excuses used to avoid hiring new faculty from under-represented groups; she recommends nineteen good practices for university presidents, provosts, deans, and departments and offers advice for academic search committees such as avoiding biased decision-making, snap judgments, or pretexts; downgrading the institutions from which candidates obtained their degree [17]. It is frequent to hear, in male-dominated circles: "We cannot lower our standards." This suggests that hiring a woman or a person from a visible minority or selecting them for a promotion or a prize will do this. However, the bar is often raised for these candidates when compared to expectations from candidates from the majority group. Criteria for judging achievement, which affects hiring, tenure, promotions, and winning awards, must reflect the quality of publications instead of their number, and the potential of the candidates rather than just their current accomplishments. Women may have had children during this period, and though their publications may be a little less than other candidates, their potential for doing excellent research and teaching may be equal or better. Universities must create policies that allow young faculty members to balance family and career. Biases can be reduced through education and sensitization programs, ensuring a fair gender representation on decision-making committees, and using proactive methods to find qualified women for positions or awards. Employers can develop objective hiring criteria, pro-actively seek women applicants, and train selection committees to recognize inappropriate questions. Creating opportunities for women to meet and fast-track women with management potential will provide mentors for younger women, and hopefully see an integration of feminine values into the culture. Instituting flexible hours can help reduce staff turnover and thus the cost of hiring and training new people. Parental leave should be available to mothers and fathers and access to affordable child care will help retain parents in today's workplace.

Progress in scientific and professional associations can be assessed by the proportion of women on important committees, receiving awards, prizes, and fellowships; invited as keynote speakers or panelists on specialty topics and plenary sessions. [18] Until we get rid of stereotypes about people's abilities and behaviours, it will be impossible to create an atmosphere of respect and trust. The predominantly male view is not the only way to create new knowledge; the diversity of perspective women can bring will undoubtedly enrich the solutions. For example, Shepherd [10] discusses how science can be improved through using qualities such as nurturing, cooperation, and receptivity. In the professions of medicine and law, new

fields appeared such as family medicine and family law when more women chose these careers. It is possible that having more women in engineering and science could lead to the development of new areas of activity.

Effecting a change of attitudes and behaviour takes time. Equity is not just an equal number of women and men; it means equal chances of success and career development. It also means that average women will be as successful as average men. If more women feel comfortable in choosing these fields, they will achieve economic independence and have more control over their lives. To achieve progress and an equitable world, men and women must be agents of change, each in their own way.

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