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Careers and achievements of the first women computer scientists, 1960-1980

Introduction

In the public domain, prizes and awards in fields of science and technology remain a stark reminder of women's invisible presence and attainments in these disciplines. In a stretch of roughly a century, over 300 men won a Nobel Prize in sciences and only 10 (3.3%) women (McGrayne, 1998). An analysis of six international prizes and awards in technology revealed that only 4 (2.9%) women compared to 136 men have been recognized (Husu & Koskinen, 2010a). During 45 years of the ACM A. M. Turing Award, presented for technical contributions to computer science, 55 men and only two (3.5%) women have been honored (in the last five years). While these figures are certainly influenced by low proportion of women in science and technology all together, there is a sizable body of evidence and examples of "deep-rooted ambivalences" about women professionals and even systematic denial of credit for their contributions to research. Furthermore, credit is attributed or taken by their male colleagues. Rossiter (1993/1995) called it the "Matilda effect" where contributions of women such as Rosalind Franklin, Lise Meitner and Marietta Blau were appropriated or attributed to their male colleagues. These numbers raise critical questions not only about participation of women in traditionally male domains of science and technology but also about the functioning of the reward system in these disciplines.

The question of why women scientists are missing from the historical record of scientific achievements and public memory of producers of knowledge is complex, as multiple factors intersect, reflect, and contribute to women's low status. While participation of women in the science and engineering labor force in the United States has been increasing since 1970s, it continues to vary by field, age, employment sector, status of the employing institution, and rank. Between 1972 and 1984 the proportion of degrees earned by women in all subjects increased dramatically, including in computer science where they just as dramatically fell after 1984 (Hayes, 2010). As a group, women are less successful than men in the number of Ph.D.s received as well as in rank and salary (Long, 2001). On average, women in science have lower publication productivity (Cole & Zuckerman, 1984; Xie & Shauman, 1998) and visibility (Long, 1992) than men. Further, it takes women longer to achieve academic ranks (Cole & Zuckerman, 1984) and, compared to men, they are promoted more slowly (Long, Allison, & McGinnis, 1993; Sonnert & Holton, 1995b). Although some high achieving women scientists do not have low publication productivity, they represent a smaller percentage of high achievers, compared to men, in the extreme right-tail of the distribution of publication productivity (see, for example, Fox, 2005). The invisibility of those women is particularly puzzling.

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Feminist researchers have long established that women's achievements, knowledge and skills have been historically invisible (Rossiter, 1982, 1995) and traditionally undervalued (Wajcman, 1991). Sociologist, Ruth Woodfield, writing about women in computing, acknowledged the existence of a general problem that women face in "having their skills recognized and rewarded" and particularly in occupations "which involve intellectual and/or social labor to a large degree" (2000, p. 189). The theoretical insights come from realizing that skills and success are socially constructed to reflect the ideals of the dominant group (male) even in science and technology fields (Philips & Taylor, 1980; Woodfield, 2000). Thus, "It is the sex of those who do the work, rather than its content, which leads to its [work] identification as skilled or unskilled" (Philips & Taylor, 1980, p. 85). As a result, work done by women is likely to be perceived as less skilled. Technical skills and competency define male identity and constitute a source of their power (Wajcman, 1991). For women to aspire to such competency is "to transgress the rules of gender" (Cockburn qtd. in Rees, 1989/1992, p. 32) and to pay a very high price by sacrificing their own gender identity (Wajcman, 1991, p. 164). The dominant culture of computing continues "to be bound up with masculine identity and interest" (Woodfield, 2000, p. 197) while the full potential of women in scientific and technological fields has not been fully realized.

Early on in the 1960s and 1970s, the computer, as a recently invented machine, was perceived to be "an object of indeterminate gender identity" that promised to redefine women's relationship with technology. However, by the 1980s computer culture had been established to reflect male values and male life-style where technical concerns presided over social concerns (Woodfield, 2000). Masculine computer culture, at its best, depicted "tireless pioneers working at the cutting edge of technical progress" and "experts whose obsession with information technology and with the 'thrill of inventiveness'[1] cannot but guarantee the reaping of intellectually and even –albeit inadvertently– socially useful and justifiable rewards" (Woodfield, 2000, p. 19). In such a culture, to be perceived as successful, women would have had to not only adopt male values but also work harder to exceed the standard of mastery and obsession with work.

Lack of appropriate qualification "has always been held to explain in part why women do not secure access to certain professional jobs" (Rees, 1989/1992, p. 28). Yet, those women who aspired for advancement and who went on to earn Ph.D. degrees in male dominated fields have earned the qualifications that would allow them to secure professional positions. Advances in computing

[1] See Glastonbury & LaMendola, 1992, p. 112.

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technologies in the second half of the 20th century created new jobs and careers, prompting the questions in regards to gender: Did men and women make equal use of these new opportunities? What factors influenced their education, career opportunities, and chances for scientific contributions? Did women scientists manage to succeed in the institution of science historically built around male attributes of success? Since masculine dispositions (qualities, thinking, expression) are part of the dominant science culture, to be knowledgeable means to possess masculine qualities (Woodfield, 2000). Likewise, when it comes to success in science, Traweek (1988) concluded "…the virtues of success, whatever their content, are associated with men" (p. 104). Defining success in terms of masculine dispositions would constitute a socially privileged meaning system in computer science that is likely to give importance and symbolic weight to some distinctions and qualifications over others in evaluations of scientific contributions. Failure to recognize excellence of women researchers may, in fact, demonstrate yet another subtle and hidden form of discrimination in the times of anti-discrimination laws, observed in other contexts of academia (see Husu, 2001).

Multiple studies have reported the operation of particularistic biases in evaluation and selection procedures in seemingly merit-based system of academia. When examining academic recruitment and selection for full professorship in the Netherlands, researchers found evidence that women's presence on the selection committee was associated with women's chances for appointment, and in predominantly male committees "similar-to-me" selections were likely to take place (van den Brink, Brouns, & Waslander, 2009). Assessment of academic merit remains "flexible and problematic" even when merit could be "seemingly deconstructed and made transparent by dividing it into subcategories according to which the rating is performed" (Husu, 2001, p. 153). A clear demonstration of how evaluations can be manipulated was presented in the same study of recruitment and selection protocols where in some cases abilities of undesired candidates were played down while those of desired candidates inflated, leading to the consistent outcome that women were less likely to be labeled as "excellent" (van den Brink, Benschop, & Jansen, 2010, p. 1474).

Though the number of women in computer science remains low (Cahoon & Aspray, 2006; Misa, 2010), the reality is that "computing was never a world without women" (Haigh, 2010, p. 69). Women were working in the computer industry, just not as engineers but as "ballistics computers" (Light, 1999), office clerks, data processing/entry workers (Haigh, 2010), punchcard machines operators (Schlombs, 2010), manual writers, secretaries, and "spouses." In all these positions women were users but not knowledge creators. The recent research on women in computing has focused on making women visible in workplaces (Light, 1999) as well as on addressing issues of underrepresentation of women in information technology (Cahoon & Aspray, 2006), their interest in information technology (Burger, Creamer, & Meszaros, 2007), gender relationship with computers (Cooper & Weaver, 2003), skills and pathways (Woodfield, 2000) and the influence of culture (Millar, 1998; Misa, 2010). However, the knowledge on the achievements and careers of the first women computer scientists is still lacking. Who were the first women to earn Ph.D. in computing? Where they able to attain high professional status?

Questions

This study aims to analyze the attainments of women pioneers in computer science[2] and assess their merit and prize-worthiness by comparing their education and career achievements to other computer scientists: 1) women who won the Turing Award, 2) men who won the Turing Award, and 3) men who did not win the award. Women of interest to this study are those who earned Ph.D. degrees and, by doing so, were well positioned to contribute to research in computer science during the period from the 1970s to the present (2011).[3] The key questions of the study are

1. How do the educational and career attainments of women computer scientists compare to those of men prize winners (and the control group)?
2. What can be done to increase the visibility of women and their achievements in computer science?

Data

<u>Identifying a sample of women computer scientists</u>

Women's invisible presence and achievements in stereotypically male professions and workplaces create a range of challenges for researchers. Have we looked in the right places? Did we try hard enough? Finding famous women researchers in computer science was not an easy task. An exhaustive search for "women pioneers" in computing/computer science through popular published and online sources produced about 60 names of women of which only half had Ph.D.s, mostly from 1960s-1980s. Prior to 1965 only five women computer science researchers had Ph.D.s while many others had bachelor's and in some cases master's degrees (including ENIAC girls). Furthermore, official biographies were mostly available for women computer science graduates with a Ph.D. of prestigious universities rather than doctoral students from other universities such as Rice, University of Wisconsin or Pittsburgh or holders of bachelor or masters degrees. The careers of women missing from biographical

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[2] Computer science is a strategic research site for the study of recognition through prize-winning. Being a new interdisciplinary field, it has multiple and competing standards of performance and lower consensus (than disciplinary fields) in judging the significance of contributions, with consequences for recognition.
[3] The time period of 1950s through early 2000 is particularly important. It is the time of development and emergence of the personal computer as we know it now and re-structuring many industries as a result of it.

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directories prompted a new set of questions: Were women's biographies missing because they did not have high enough positions or because they were women (hence not professionals)? How might one go about finding out what happened to those women? It was evident that to find the names of women pioneers required more creative means.

Using the National Science Foundation (NSF) statistics[4] as guidance for how many women have earned a computer science degree, I retrieved a list of graduates who received a Ph.D. in computer science between 1970 and 1976 from the ProQuest *Dissertations and Theses* database.[5] Since the database listed authors' first and middle names, I was able to identify gender and select only women from the names of dissertation authors.[6] Table 1 lists the available information on women Ph.D. holders in computer science and the number of women identified and included in this study.[7]

Table 1. Number of Women Ph.D. holders in Computer Science, 1966-1976

Year	Number of Ph.D.s in Computer Science [NSF]	Number of Ph.D.s awarded to Women [NSF]	% of Ph.D.s awarded to Women	Number of Women Found	Number of Women Included in the Study
1966	19				
1967	38	1	2.6		
1968	36				
1969	64	2	3.1	1	
1970	107	2	1.9	5	1
1971	128	3	2.3	5	2
1972	167	12	7.2	16	3
1973	196	15	7.7	16	10
1974	198	9	4.5	15	1
1975	213	14	6.6	16	5
1976	244	23	9.4	18	8

[4] National Science Foundation [NSF], Division of Science Resources Statistics. (2006). *U.S. Doctorates in the 20th Century*, NSF 06-319, Lori Thurgood, Mary J. Golladay, and Susan T. Hill, Arlington, VA.

[5] By filtering the subject heading (SU) using a keyword "computer" I retrieved a list of graduates from departments of computer science and its variations (more precisely those departments that had computer in its title) for and including year 1969, and then for each year 1970-1976. The first dissertation in computer engineering is from 1940 by Mehmet Akin Sencer, University of Ottawa (Canada) (excluded due to location outside of U.S.). The first woman to receive a Ph.D. in computer science, according to ProQuest Dissertations and Theses database, was Louise Jane Allen from the University of Western Ontario (Canada) with her Ph.D. dissertation "An analogue computer for the one dimensional Schroedinger equation" completed in 1954. Except these two exceptions all pre-1970 women graduates were considered for the study.

[6] For non-Western names I consulted internet and in many cases was able to find a professional profile of a person or a clue about his/her gender.

[7] From 93 women some information was available in biographical and internet sources for at least 59. However, only 18 were listed in the *American Men and Women of Science* directory (all published editions to date) and two were listed in other biographical sources (*The Complete Marquis Who's Who*). For two women scientists curriculum vitas were available online. Six (plus one for who some information was missing) scientists were contacted by email because no information was available for them.

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Total Over Years	1410	81	45.4	92	30

Note: The data on the number of Ph.D.s in Computer Science come from National Science Foundation [NSF], Division of Science Resources Statistics. (2006). *U.S. Doctorates in the 20th Century*, NSF 06-319, Lori Thurgood, Mary J. Golladay, and Susan T. Hill, Arlington, VA.

Only one third (out of 92) of the identified women computer scientists with a Ph.D. had a biography and some academic experience in their professional careers. For the other two thirds of women graduates, for whom published biographies were not available, internet searches provided clues that they were either industry researchers or professionals assuming a variety of responsibilities. For 38% (out of 92) no biographical references were available in online sources (not even a website, or professional contact). The selected one-third (N=30) of identified women is a group of researchers who persisted in computer science and who had either an academic career or a mixed career combining industry and academic experiences.[8] These women Ph.D. degree holders in computer science in 1970-1976 who persisted in their field are an important group of researchers because for the last 35-41 years (as of 2011), they were eligible candidates for awards. How far they were able to advance in their career is of outmost interest to this study.

To assess educational and career attainments of the selected group of women computer scientists, I collected biographic and bibliometric data. The biographic information came from the *American Men and Women of Science* directory (multiple editions). Biographical entries usually contain basic demographic data (date and place of birth, marriage year, children), information on education, work experiences, membership in professional associations, and honors received. I extended the biographical data by collecting bibliometiric data from the Thomson Reuters *Web of Knowledge* database, specifically the *Science Citation Index Expanded* (SCI-EXPANDED).[9] The *Web of Knowledge* provided bibliometric information on the number of publications, maximum citation count and the number of collaborators.

Method

In this study I used descriptive statistics to summarize educational and career attainments of women researchers. Then I used a comparative approach to assess their achievements in relation to other computer scientists: 1) women who won the Turing Award, 2) men who won the Turing Award, and 3) men who did not win the award.

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[8] I decided not to include women only with industry experience because 1) industry has slightly different indicators of success and 2) because the reference group of Turing Award winners and non-winners also do not include industry only researchers.

[9] One of the Turing Award winners got his Ph.D. in political science. The Social Sciences Citation Index (SSCI) was used to track his publications that were unlikely to be present in the Science Citation Index prior to the Turing Award.

According to the normative perspective, awards in science are distributed based on meritocratic evaluation involving impersonal criteria and previously confirmed knowledge and not "personal or social attributes of protagonist" (Merton, 1973, p. 270). Specifically, a strong publication record may constitute evidence of scientific productivity and thus of a significant contribution to science, possibly worthy of an award. Alternatively, the quality of scientific contribution can be recognized as reflected by citation counts indicating contribution's impact, usability and award-worthiness. Furthermore, career attainments may also be influenced by scientists' network of collaborators who represent his/her *social capital* (Granovetter, 1973, 1985; Burt, 1992; Coleman, 1988, 1990; Lin, 1999, 2002) and can bring various resources and rewards such as jobs, information, trust and possibly recognition. The most visible and measurable social network that a scientist has is of his/her collaborators. The collaborators could be instrumental in submitting nominations, writing letters of recommendation or evaluating candidates who they know. Additionally, scientific career attainments may include and reflect employment prestigious organizations. Researchers have long established that being at a major university positively affects the likelihood of being recognized (Crane, 1965; Long, 1978). Finally, to be considered for technical awards such as the Turing Award in computing, being known by key decision-makers in the ACM scientific community may be important. Professional associations and study societies are committed to promoting their occupations and building their own legitimacy and, as a result, become instrumental in formalizing elite professional status of some of its members (Larson, 1977; Wilensky, 1964; Abbott, 1988). Therefore, proximity and visibility in an organization and professional networks may be a prerequisite for professional success.

Variables

Early career advantage: a fellowship, a publication with advisor, first job in top department

Previous empirical studies reported that elite and recognized scientists attend a handful of selected universities (Zuckerman, 1973; Cao, 1999). The importance of educational settings was conveyed by scientists themselves who particularly acknowledged "the quality of regular science instruction, peers' attitudes toward scientific or academic excellence, fellowships and financial support, mentors and role models, and special educational environments" (Sonnert & Holton, 1995a, p. 166). As a result, fellowships were included in the present study as a type of exclusive reward as opposed to research assistantships that are more common (see Gaughan & Robin, 2004; NSF, 2006). Publications with mentors/advisors were included because they positively affect scientists' subsequent productivity (Long & McGinnis, 1985) and later career placement (Fox, 2003; Crane, 1965; Zuckerman, 1967). The rank of the doctoral department and sponsorship by the mentor (and not simply publication productivity) also

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influence the prestige and location of a scientist's first job (Cole, 1979; Long, Allison, & McGinnis, 1979). First job is a critical point in scientists' career paths, which I included in the assessment of career attainments.

Number of Publications

High research productivity typically involves a relatively high number of publications and contributions to multiple projects during a given period. By being prolific, a scientist can become visible and influential in the scientific community. Publication productivity, measured by the rate of publications, was found to be the best predictor of how peers judge fellow scientists (Cole & Cole, 1973; Sonnert, 1995c). This finding is consistent with prior observations that eminent scientists tend to be productive researchers (Allison & Stewart, 1974; Fox, 2005; Reskin, 1977; see also review by Fox, 1983). Therefore, the rate of publications was chosen for the assessment of career attainments.

Highest Citation

A contribution worthy of an award is likely to have some outstanding characteristics that made substantial impact on the community which would be reflected in the number of citations to a publication describing that particular finding or invention. I used citation count of a single most cited publication as a measure of the impact of the contribution. Highly cited publication can indicate usefulness of a contribution (Long, 1992) and grounds for recognition.

Eminence: Number of Awards

Accomplished scientists typically receive large number of awards (positive reinforcements) throughout their careers (Cole, 1979). Prior recognition and peer esteem together with past successes are likely to increase the probability of additional recognition. This phenomenon, known as *cumulative advantage,*[10] can operate together with the *Matthew Effect*[11] and increase the chances of receiving new awards for scientists already recognized. As such, I used the number of the awards as a measure of eminence. In addition, because induction into exclusive societies such as in the National Academies of Sciences or Engineering (NAS, NAE) marks exceptionally high status[12] and represents one of the highest

[10] Cumulative advantage are "the social processes through which various kinds of opportunities for scientific inquiry as well as the subsequent symbolic and material rewards for the results of that inquiry tend to accumulate for individual practitioners of science," see Merton (1988), p. 606.
[11] Matthew Effect is "accruing of greater increments of recognition for particular scientific contributions to scientists of considerate repute and the withholding of such recognition from scientists who have not yet made their mark," see Merton (1968/1973), p. 446.
[12] Garfield (1977) found that the membership of Nobel Prize winners in national academies was very high (92%).

achievements for U.S. scientists (Cole & Cole, 1973; Feist, 1997), the induction into the National Academy of Science and Engineering was also noted.

Number of Co-authors, Turing Co-authors/Committee members

In addition to bringing intellectual capital, collaborators are scientists' social capital through which they can access other resources (powerful networks, information, jobs, collaborative opportunities, consulting (see Burt, 1995; Coleman, 1988; Granovetter, 1973; Lin, 2002). Social capital, embodied in relationships among researchers, generally takes on one of three forms: "obligations and expectation, which depend on trustworthiness of the social environment, information-flow capability of the social structures, and norms accompanied by sanctions" (Coleman, 1988, p. S119). In the scientific community, as in other communities, moral bonds of trust not only facilitate knowledge transfer but also may be used in evaluation of peers in the decisions concerning rewards. Collaborators that are most knowledgeable about the significance of shared research are likely to have similar values, outlook on research frontiers and interest in promoting their research area.

Employment in Elite Organizations

Researchers have long established that being at a major university positively affects the likelihood of being recognized (Crane, 1965; Long, 1978). Scientists in prestigious departments also tend to be productive as productivity was found to conform to the norms of the department (Allison & Long, 1990). Being in a highly ranked department increases one's visibility in research community. In fact, positional and reputational successes were found to influence each other (Cole & Cole, 1973). For these reasons, department affiliation (measured at the 27th year after Ph.D.) was one of the measures of career attainment.

Visibility in ACM: publications

Since the Association for Computing Machinery presents the Turing Award, the visibility in the ACM is important for recognition. A high level of visibility through networking (interactions, communication, collaborations) was found to distinguish the careers of more successful compared with less successful scientists (Sonnert & Holton, 1995a). Professional organizations often become focal places for research community interactions and dissemination of new knowledge, and thus, visibility in ACM was considered in the analysis of career attainment.

Findings

Educational Attainments

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The group of women who persisted in mixed (academic and industry) careers in computer science is a distinguished group of researchers. Table 2 provides a summary of where women received their Ph.D. degrees and Table 3 summarizes their career attainments. If we are to compare women to men computer scientists in mixed careers (though in slightly larger time frame, from 1942-1981), we find that although both groups attended top five universities for computer science in the United States, more (50% out of 30) men Turing Award winners attended top five universities, compared to 30% (9 out of 30) of women. Additionally, the universities where women received their Ph.D. degrees were more *diverse* while men Turing Award winners attended fewer top universities, representing a more *converging* pattern of schools compared to women.

Table 2. Universities Where Women Scientists Received Their Ph.D. Degrees, N=30

		Women (n=30)		Men (n=30)	
	University	**Number of Ph.D. Degrees**	**% of Group Total Ph.D. Degrees**	**Number of Ph.D. Degrees**	**% of Group Total Ph.D. Degrees**
Top Five Universities for Computer Science	Stanford	4	13.33	5	16.67
	MIT			4	13.33
	UC Berkeley	2	6.67	3	10
	CMU	3	10	2	6.67
	Cornell			1	3.33
Total		9	30	15	50
Other Universities	Princeton			5	16.67
	Harvard	1	3.33	5	16.67
	U of Illinois	3	10	1	3.33
	Cal Tech			2	6.67
	Syracuse U	2	6.67		
	UT at Austin	2	6.67		
	John Hopkins	1	3.33		
	Northwestern U	1	3.33		
	Penn State	1	3.33		
	Rice U	1	3.33		
	Southern Methodist U	1	3.33		
	U of Chicago	1	3.33		
	U of Colorado	1	3.33		
	U of Delaware	1	3.33		
	U of Michigan			1	3.33
	U of Virginia	1	3.33		
	U of Washington	1	3.33		
	U of Wisconsin	1	3.33		
	UC San Diego	1	3.33		
	UCLA	1	3.33	1	3.33
Total		21	70	15	50

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Career Attainments

Early career advantages matter because inequality emerging during the early stages of scientific careers is likely to be based on particularistic selection and sponsored mobility, since a young scholar has not yet demonstrated his/her productivity (Zuckerman, 1988, p. 530). The available data indicates that women scientists were just as likely to publish with their advisors as the control group of men, while Turing Award winners were twice as likely to publish with their advisors.

Fewer women scientists were able to find first jobs in top departments for computer science while almost five times as many Turing Award winners started their careers in top five departments. Considering that particularly during 1970s, universities were likely to hire their own graduates or those from similarly prestigious departments (Burris, 2004; McGee, 1960; Hargens & Farr, 1973; Long, 1978; Long, Allison, & McGinnis, 1979; Long & McGinnis, 1981), scientists who attended top departments had advantages in securing jobs in a similarly prestigious department. It is all too common that mobility in academia is "mainly horizontal or downward and seldom upward" (Burris, 2004, p. 249). Even here women were at a disadvantage. Only three women scientists out of nine, who attended top computer science programs, found jobs in top five universities. In comparison, almost the same number of Turing Awards winners, as those who attended the top universities and half of the control group computer scientists, found jobs in top five universities. Overall, 75% of women found first jobs in the academic sector (80% of men winners and non-winners, see Nikiforova, 2012),[13] however, only 55% stayed in academia 27 years later, of which only two women (9% of the 22) were working in top computer science departments (see *location in an elite institution* in Table 3).

The *productivity* of women scientists over the course of their careers (as of 2011) was lower than that of Turing Award winners (at the time of award) but higher than productivity of the control group of computer scientists. Women published on average 25.7 publications, compare to 28.2 for Turing Awards scientists, and 21.5 of the control group of men scientists. Similarly, the *impact* of women's publications, measured by maximum citations to the most cited publication, was lower than the impact of Turing Award winners but higher than the control group of scientists. Women, on average had about 110 citations, compared to 198.5 for Turing Award winners (at the time of the award), and 90.9 for the control group.

[13] For this variable N=24 because data was missing for six women.

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One of the most obvious differences between women and men, Turing Award winners and non-winners, was in the number of prior *awards*. As a group, Turing Award winners received about 51 honors and awards prior to the Turing Award while women and the control group scientists received three to four times fewer awards (14 and 12 awards respectively). However, each of the two women who was honored with the Turing Award had two awards prior to receiving the Turing Award. The same pattern follows the membership in the National Academies of Science and Engineering: more (half of the group) men Turing Award winners, compared to women and the control group, have been elected into these exclusive societies. However, both women computer scientists who won the Turing Award were NAE members.

A rather surprising finding was that women scientists had a larger *number of collaborators* than men award winners and non-winners. On average, women had about 34.4 collaborators in their professional careers, while men Turing Award winners had only 25.7 and non-winners had even fewer, 19.9 collaborators.[14] However, in regards to the *type of collaborators*, the patterns remained consistent, more Turing Award winners had collaborators who already won the Turing Award (24) and collaborators Turing Committee members (15). Women had less than half as many (4) Turing Award winners among their collaborators but more Turing Committee members (6) compared to the control group scientists (2). Both women computer scientists who won the Turing Award had one Turing Award winner in their collaborator network and two Turing Committee members, providing additional evidence of the importance and utility of professional networks of collaborators.[15]

Another significant difference between Turing Award winners and non-winners was in *visibility in the ACM*, in particular, in the publication venues. Almost all Turing Award winners (29) published in ACM journals, while slightly over half of women (16) and control group scientists (17) published in ACM journals. In addition, men Turing award winners (10) and non-winners had more (4) awards from the ACM compared to women scientists (1). Women and men non-winning scientists were more likely to have done some service activity for the ACM, compared to Turing Award winners.

Discussion

[14] One obvious explanation for this is that men's publications and co-author count was collected for a time period of about 27 years (on average) after they received a Ph.D., while the same statistic was collected for women for about 37 years (on average) after they received their Ph.D. degrees. As such, women had more time to publish and collaborate.

[15] It is also important to note that according to available data, 14% of Turing Committee members, since its existence, were women, four of them were part of this study.

The studied group of women computer scientists is a highly selective group of researchers who persisted in mixed careers in industry and in academic sectors. However, their careers were not successful at every stage. The findings indicate that women researchers started with fewer career advantages than the comparable group of men scientists in terms of publications with advisors and first jobs in top computer science departments. About 13% of women scientists and 30% of Turing Award scientists published with their advisors. Only one third of women scientists out of the nine who attended top computer science programs found first jobs in top five universities, while almost all Turing Award winners and half of the control group computer scientists, who attended the top universities, found jobs in top five universities. Starting with few advantages meant that women were less likely to accumulate other advantages, owing to the cumulative nature of success in science (Merton, 1968/1973; Zuckerman, 1977). In fact, some researchers noted that women tend to accumulate more disadvantages over the course of their careers rather than advantages (Castaño & Webster, 2011).

As a group, women were less productive in publications than Turing Award winners but more productive than the control group of scientists. However, a small portion of women high achievers had very high publication productivity (and high impact citations) that matched and in many cases exceeded that of Turing Award winners (see also, Fox, 2005). The overall publication productivity of women was likely to contribute to their low visibility that was also reflected by other variables. Women's publications received fewer citations than those of Turing Award winners. Similar to the control group of scientists, they received 3.6 times fewer awards than Turing Award winners (prior to their award). Even though women had many collaborators, among them, there were fewer Turing Award winners (6 times less) and Turing Committee members (2 times less) than among those of Turing Award scientists. Low publication rates of women and the control group scientists in ACM journals suggest their relative distance from the ACM community and possible contributions on the margins or in other communities for computer professionals.

The situation of women in computer science seems to follow the general pattern of women in science in which women's low productivity is "both cause and effect of their career attainments" (Fox, 2006, p. 23). In the study of Turing Award scientists, I found a high correlation among scientists located in top institutions, receiving early career advantages and having resourceful collaborators who are already Turing Award winners and Turing Committee members (Nikiforova, 2012). This pattern suggests that access to top institutions and accomplished colleagues was perhaps a key to achieving success in science. With access to prestigious and highly visible institutions comes visibility to the scientific community, prize-winning colleagues and Turing Committee members. Employment in prestigious universities is also associated with higher publication rates than employment in less prestigious universities (regardless of prior productivity, once position is obtained, later productivity conforms to departmental expectations, see Long &McGinnis, 1981), higher citations and awards (as part of the "halo" effect of institutional location, Crane, 1965). Indeed, visibility in the ACM, prior awards and location in an elite institution were most effective variables in predicting recognition with the Turing Award (Nikiforova, 2012).