Essays of an Information Scientist: Of Nobel Class, Women in Science, Citation Classics and Other Essays, Vol:15, p.259, 1992-93 Current Contents, #11, p.3-13, March 15, 1993

Current Comments®

EUGENE GARFIELD
INSTITUTE FOR SCIENTIFIC INFORMATION®
3501 MARKET ST., PHILADELPHIA, PA 19104

Women in Science. Part 2. The Impact Enigma— J. Scott Long on Why Women Biochemists' Papers Are Cited More than Men's

Number 11 March 15, 1993

Introduction: The Productivity Puzzle

Two weeks ago the first part of an article by sociologist J. Scott Long, Indiana University, Bloomington, on sex differences in scientific productivity was reprinted in *Current Contents®*.[1,2] It compared the number of papers published by a sample of 556 male and 603 female biochemists over a 17-year period. During the first three career years, males averaged 26 percent more publications. The percentage differences increased to 91 percent by year 9 and declined to 59 percent by year 17.

Long's analysis provided interesting details on how men and women differ in the distribution and stability of productivity. But his findings confirmed previous studies documenting a well-established difference—women publish fewer papers. These studies were recently reviewed by Harriet Zuckerman, Andrew W. Mellon Foundation, New York.[3] Although various reasons for this difference have been suggested—marriage, motherhood, cultural barriers, sexual discrimination, and so on—none have adequately accounted for it. In 1984, Zuckerman and Jonathan Cole, Columbia University, called this the "productivity puzzle."[4]

The Impact Enigma

In part 2 reprinted here, Long turns to the question of sex differences in *citation*. He found no significant differences in average citations per *author* in the first three years. However, mean citations drop substantially for women—and increase for men—beginning in year four. At year 10, average citations for men level off while increasing for women. By year 17, men and women show nearly identical averages. Not surprisingly, he concludes that these trends are completely accounted for by differences in average numbers of publications, confirming Cole's and Zuckerman's earlier findings.[3,4]

What is perhaps surprising is Long's finding that women have significantly higher impact than men in terms of average citations per *paper*. Males averaged seven to nine citations per paper, which was fairly stable over the 17-year period. In contrast, papers by women had an impact of 9 to 13, which steadily increased from years 10 to 17. By year 17, the average woman's paper was cited 1.5 times more frequently than the average man's paper. In contrast, Cole and Zuckerman found that papers by women in six scientific fields were cited on average just as often as those by men.[3,4]

As both Long and Zuckerman have pointed out, it is remarkable that women have either equal or higher impact than men since women tend to have relatively lower-ranking appointments, poorer research facilities, and less active research programs.[3,5] In the following reprint, Long speculates on the possible reasons for this. Acknowledging that more detailed analyses are needed, he poses an intriguing question: "How is it that females consistently publish less and, by most accounts, are in more marginal scientific positions than males yet receive more citations of the articles that they publish?" It will indeed be interesting to see how this "impact enigma" is ultimately explained in future studies.

*****

My thanks to Al Welljams-Dorof for his help in the preparation of this essay.

REFERENCES

1. **Long J S.** Measures of sex differences in scientific productivity. *Soc. Forces* 71:159-78, 1992.
2. **Garfield E.** Women in science. Part 1. The productivity puzzle—J. Scott Long on why women biochemists publish less than men. *Current Contents* (9):3-13, 1 March 1993.
3. **Zuckerman H.** The careers of men and women scientists: a review of current research. (Zuckerman H, Cole J R & Bruer J T, eds.) *The outer circle: women in the scientific community.* New York: Norton, 1991. p. 27-56.
4. **Cole J R & Zuckerman H.** The productivity puzzle: persistence and change in patterns of publication on men and women scientists. (Maehr M L & Steinkamp M W, eds.) *Advances in motivation and achievement.* Greenwich, CT: JAI Press, 1984. Vol. 2. p. 217-56.
5. **Long J S.** Problems and prospects for research on sex differences in the scientific career. (Dix L S, ed.) *Women: their underrepresentation and career differentials in science and engineering.* Washington, DC: National Academy Press, 1987. p. 157-69.

Measures of Sex Differences in Scientific Productivity*

J. SCOTT LONG, *Indiana University*

Abstract

Satisfactory and robust explanations of sex differences in scientific productivity remain elusive. This article provides a multidimensional, longitudinal description of the productivity of male and female biochemists. Several findings have implications for explaining differences in productivity. Sex differences in the numbers of publications and citations increase during the first decade of the career but are reversed later in the career. The lower productivity of females results from their overrepresentation among nonpublishers and their underrepresentation among the extremely productive. Among biochemists who publish, differences cannot be explained by patterns of collaboration, which are nearly identical for males and females, with one exception: females are much more likely to collaborate with a spouse. The smaller number of citations received by females results from their fewer publications, not from the quality of their publications. Papers by females on average receive more citations than those by males. These and other findings suggest future directions for research to understand sex differences in scientific productivity.

COLLABORATION

Sex differences in the number of papers published may be distorted by the effects of collaboration. Those who have more collaborators may publish more papers than those with fewer collaborators. Collaboration with a mentor, with colleagues, and with a spouse are considered in this section.

Collaboration with a Mentor

Collaboration with a mentor is integral to graduate study (Long 1990; Long & McGinnis 1985; Reskin 1979). Three measures of this collaboration are considered: the percent of a cohort that collaborates with a mentor on at least one paper; the average percent of a student's papers that are written in collaboration with a mentor;

* *I would like to thank Rachel A. Rosenfeld, Lowell L. Hargens, Thomas F. Gieryn, and an anonymous reviewer for their comments on this article. Funding was provided by grant SES-8304029 from the National Science Foundation.* *Direct correspondence to the author at Indiana University, Department of Sociology, 744 Ballantine Hall, Bloomington, IN 47405.*

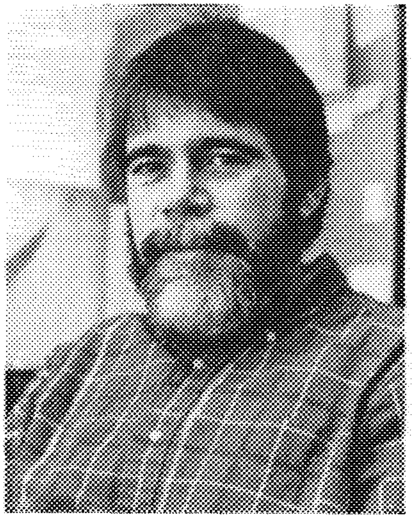
and the average number of papers a student writes with the mentor.

There are no statistically significant differences in the percent of males and females from the 1956 cohorts who collaborate with a mentor during the first six years after receiving their Ph.D.'s. The percent collaborating begins at around 55% and drops steadily, to around 12% in the sixth year.[1] While the percent of *students* who collaborate with a mentor is equal for males and females, 8% more of a female's *articles* are written in collaboration with a mentor. This difference is related to more females publishing all of their papers with a mentor and fewer publishing some without such collaboration. The greater average productivity of males during the first six years almost perfectly offsets the lesser percent of their articles written with a mentor, resulting in males and females having almost exactly the same average number of publications per year produced in collaboration with a mentor. Thus, sex differences in mean publications cannot be explained by the absolute number of publications written in collaboration with a mentor, but other analyses have shown that differences in the processes of collaboration have some effects (Long 1990).

The percent collaborating with a mentor for the 1950 and 1964 cohorts of females is approximately 3 percentage points higher than for the 1956 cohort. The greater percentage for the older cohort may reflect the more marginal position of females during the period; the greater percentage for the later cohort is likely to be a result of changes in collaboration patterns over time, which I discuss below.

Collaboration Later in the Career

Collaboration with a mentor is soon replaced by collaboration with colleagues. The frequency of such collaboration is reflected in the average number of authors per article.[2] Figure 1 presents results for the 1956 cohorts. The lines trace almost identical J-curves. The average number of authors starts at 2.8 and drops to 2.5 in the ninth year, followed by a steady increase to 3.1 in year seventeen. One interpretation of these results is that collaboration with



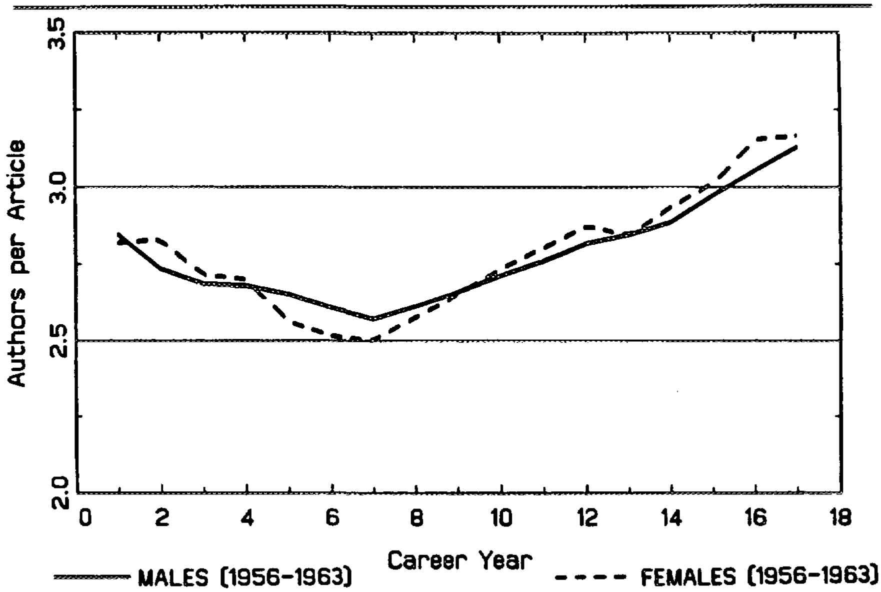
J. Scott Long

more senior researchers that begins during graduate and postgraduate study gradually declines as a scientist develops an independent research program. As a scientist's reputation develops, collaboration with junior colleagues and students increases.

Although changing levels of collaboration may reflect different stages in scientists' careers, comparisons with the 1950 and 1964 female cohorts suggest that the increase in the average number of authors also reflects historical changes in collaboration. While each cohort shows an increase in collaboration over time, later and more gradual increases are evident among those who received their Ph.D. in earlier years. The increases in collaboration over time shown in Figure 1 reflect both changes in the career stage and historical trends toward more collaborative work.

Some authors (cf. Lindsey 1980; Price & Beaver 1966) have argued that measures of productivity must be adjusted to account for multiple authorship. Adjusting publication counts for collaboration does not change the pattern of sex differences. Adjusted and unadjusted counts are highly correlated, with correlations ranging from .90 to .95, and males and females have nearly identical levels of collaboration. In keeping with the results of Cole and Zuckerman (1984), sex differences in levels of publi-

FIGURE 1: Average Number of Authors per Article by Career Year



cation are not the result of differences in patterns of collaboration.

Collaboration with a Spouse

Males and females differ in the degree of collaboration with their spouse. Measurement of spousal collaboration is based on the working assumption that coauthors with the same last name are married. This assumption is approximate, since scientists with the same last name may be unrelated; relatives with the same last name need not be married; and spouses may have different last names. However, these problems should not differentially affect the counts for males and females, and consequently differences between the estimates for males and females should be unbiased. For simplicity, I refer to this measure simply as collaboration with a spouse.

Sex differences in collaboration with a spouse are large. Between 1% and 2% of the male cohort collaborates with their spouse, with slight increases over time. For the 1956 female cohort, the percent jumps from 2.1 to nearly 10 in the third year and fluctuates around that level. The jump around year three may reflect the marriage of females immediately after receiving their Ph.D. or during their postdoctoral fellowship. For the 1950 cohort, the percent starts around 2 and steadily increases to 12. For the most recent female cohort, the level of collaboration starts at around 4% and gradually declines to around 3% in year seven, followed by a sharp increase over a two-year period to over 6%.

Since 94% of males are married compared to 67% of females, fewer females are "at risk" of collaborating with their spouse. On the other hand, female scientists are more likely to be married to another Ph.D. Regardless, a significant proportion of females appear to collaborate with their spouse, whereas very few males seem to do so.

AUTHOR POSITION

While the average number of authors per article is remarkably similar for males and females, there are interesting and surprising differences in author position. In deciding author position, collaborators are often ambivalent about such "trivial" matters as name ordering and about the fair allocation of credit for a scientific contribution (Zuckerman 1968). Zuckerman (1968), Heffner (1979), and others find that scientists take an active interest in name ordering. While many mechanisms have been devised for dealing with this potentially divisive issue, patterns discovered by Zuckerman (1968) and most scientists' personal experiences suggest that ordering is rarely a matter of chance.

If ordering is a matter of chance, the average author positions for males and females should be similar. Figure 2 compares these positions for the 1956 cohorts.[3] Females have a higher average author position in years one through three, when collaboration with a mentor is a major factor. At that point there is a switch, as the average author position for males increases and that for females slowly decreases. Females show a steady rise in year eight that is parallel to but one-fourth of a position in *front* of males. While it is possible that females are excluded as authors of papers in which they make contributions (Heffner 1979), there is no evidence that they are relegated to the back of the author list when they are included.

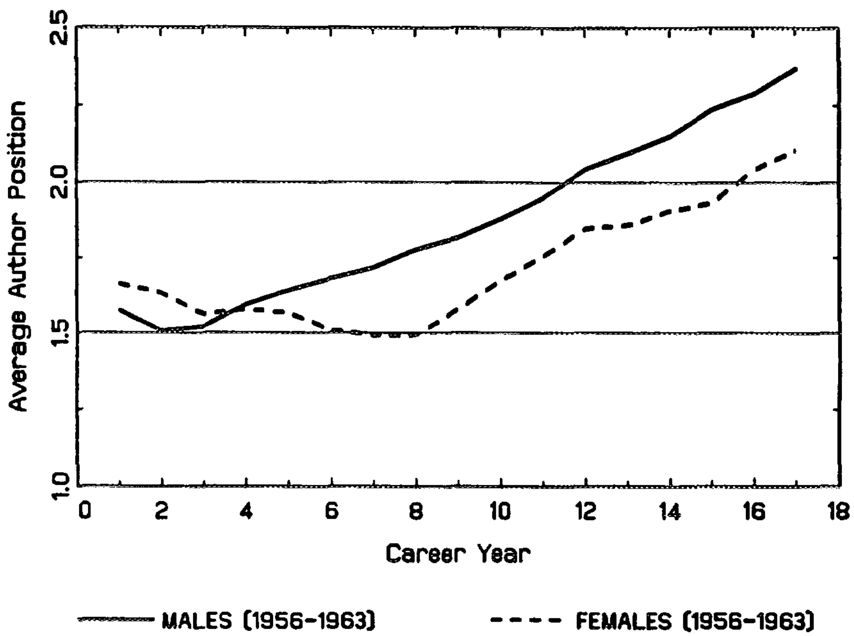
There are several possible explanations for these results. First, the results may be spurious. If some scientists assign position according to the first letter of the last name and the female sample happens to have last names with first letters that appear earlier in the alphabet, the alphabetizing of author positions might explain our findings. Tests of the average letter of the last name indicate that this is not the case (t=.41, df=555, p=.68).[4] Second, females may benefit from noblesse oblige, whereby eminent members of a collaboration allow less eminent members to have a more prominent position in the name ordering. While noblesse oblige is known to operate among the most prestigious scientists (Zuckerman 1977), it is unlikely to be a major factor affecting decisions made by rank-and-file scientists. Furthermore, noblesse oblige should equally affect marginal males and females and not result in sex differences. Third, prominent author positions of females may reflect chauvinistic behavior, whereby females are given these positions for the same reason that some males hold doors open for females. This notion runs counter to an entire literature suggesting that females are not recognized for their contributions in science. Fourth, males may more often be senior professors or directors of labs with more students and researchers working under them. Such males may find themselves junior authors on papers in which they played a minor role or, through a process of noblesse oblige, may allow their students to have more prominent authorship positions. This idea is consistent with the small positive correlations between average position and number of articles for males. The correlations average .14 and increase over time. Beyond year five, these values are significant beyond the .01 level. The correlations are smaller for females and significant only in year thirteen.

IMPACT AND UTILIZATION

Since articles can be used or ignored, measures of productivity based solely on counts of articles can be misleading. Measures based on citations of published papers or weighted by the quality of the journals in which the papers are published may be better indicators of a scientist's contribution to the body of scientific knowledge (cf. Cole & Cole 1973). Two measures of impact and utilization are considered. The first measure weights each publication by the impact of the journal in which it is published. The impact factor measures the average number of citations received by the average article published in the journal (Garfield 1972). This measure behaves almost identically to unweighted counts of publications and is not considered further. The second measure counts citations received by a scientist's papers. These counts are made by looking up citations to both first- and junior-authored papers in *Science Citation Index*® for each of the three years following a paper's publication.

Article counts and citation counts are highly correlated, with correlations ranging from .81 to .93 for the 1956 cohorts. There are several patterns to the correlations. Correlations for females are slightly

FIGURE 2: Average Author Position, by Career Year

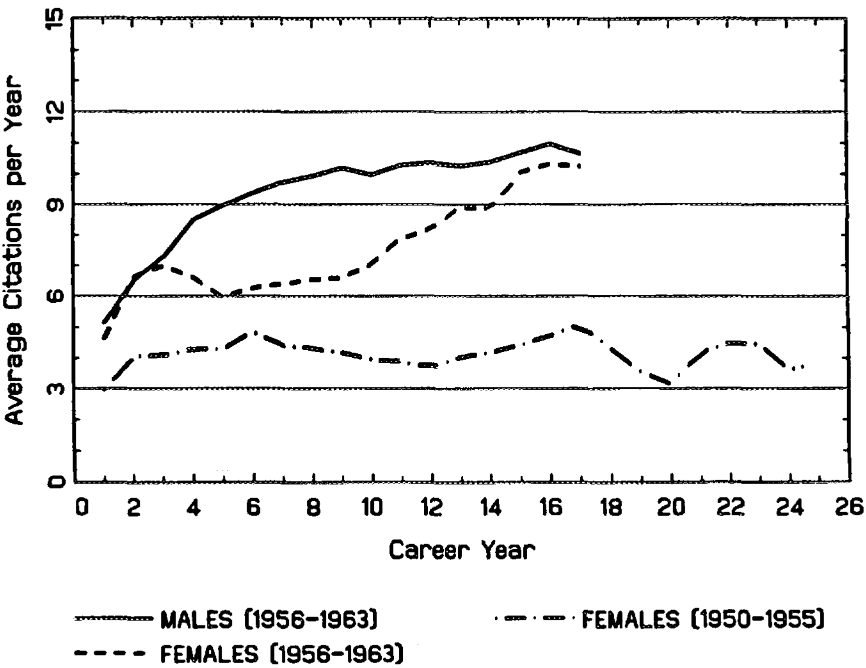


higher due to fewer females who are outliers (i.e., who have few citations and many articles or many citations but few articles). Second, correlations tend to be lowest during the start of the career and more stable and higher later in the career. This finding is consistent with the greater reliability of the yearly measures later in the career since these measures are based on the sum of more articles (Allison 1977). Finally, since scientists with no published articles necessarily have no citations, a substantial number of individuals in each year have zero articles and zero citations. To test whether this inflates the correlations, correlations were run excluding those without publications. No systematic differences were found.

Even though numbers of publications and citations are highly correlated, comparisons of mean levels for males and females provide strikingly different results, as shown in Figure 3. The 1956 cohorts of males and females are more similar in level of citation than publication (cf. Figure 4). In the first three years, there are no significant differences. Year four shows a substantial decline in the number of citations received by females, while the number increases for males. Over the next six years the means increase, but more rapidly for males. At year ten the trend changes, with average citations for males leveling off and the average for females increasing. By year seventeen, levels of citations are nearly identical, even though males have more articles to be cited (see Figure 4). I return to this point later.

As with prior measures, females from the 1964 cohort are very similar to those from the 1956 cohort, while major differences are found with the 1950 cohort. The 1950 cohort of females has significantly fewer citations per year than the other cohorts. While part of this difference may be due to the steadily increasing number of journals evaluated by *Science Citation Index®*, this increase cannot totally explain the observed patterns. If the plots are offset by six years so that the time axis is in calendar years rather than career years, the differences persist. Once again, females

FIGURE 3: Average Number of Citations, by Career Year



who obtained Ph.D.'s prior to 1956 are significantly less productive than later cohorts.

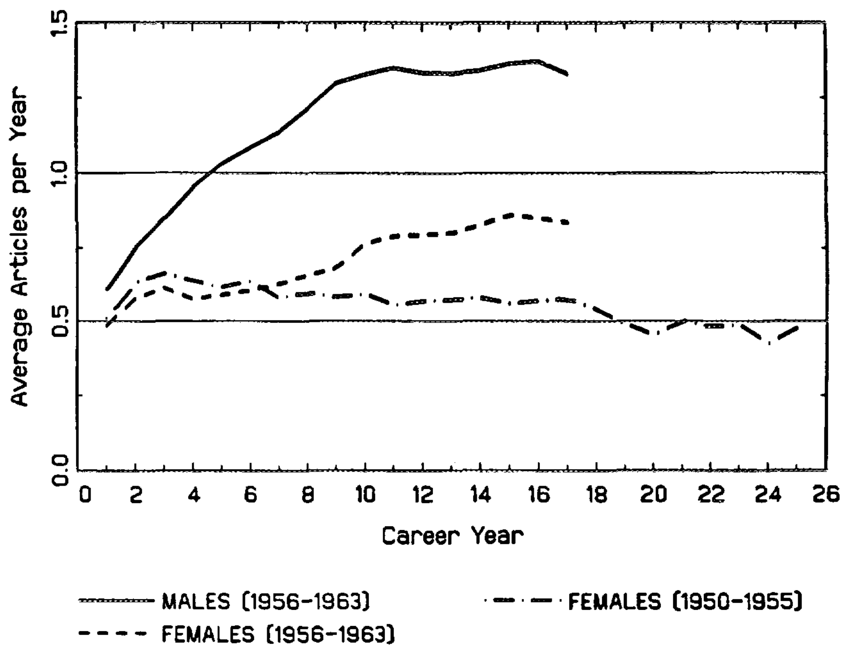
Citation counts are even more highly skewed than article counts, as shown by the box plots in Figure 5. The 25th percentiles are 0 for all years, except years three and four for males, when they are .30. For males the median begins at 1.7, rises to 3.0 by year three, and remains around that level until year twelve, when it gradually falls to 1.7 by year seventeen. The medians for females are substantially lower, starting at 80% of the level for males, dropping to 33% by year seven, and remaining around that level until year fifteen, when the median rises to about 50% of the level for males. Even though sex differences in mean levels of citations are less than those of publications, the differences in median levels are greater. The least cited half of the females is much less cited than the least cited half of the males.

Sex differences in mean levels of citations are so close because of the strength of the upper quartile of the female sample. The 75th percentiles are about equal to the means for both males and females. The range from the 75th percentile to the 95th percentile is often larger for females, and by year fifteen the 95th percentile for females is higher than that for males. By year fourteen the mean number of citations of the most cited 5% of females in the 1956 cohort is greater than that of the most cited 5% of males.

CITATIONS PER ARTICLE

Since there are greater sex differences in publication counts than in citation counts, *the average paper of a female scientist is cited more frequently than the average paper of the male scientist*, as shown in Figure 6.[5] The average male's papers receive between seven and nine citations during the first seventeen years of the career; the average female's papers receive between nine and thirteen citations, with the rate in-

FIGURE 4: Average Number of Articles by Career Year

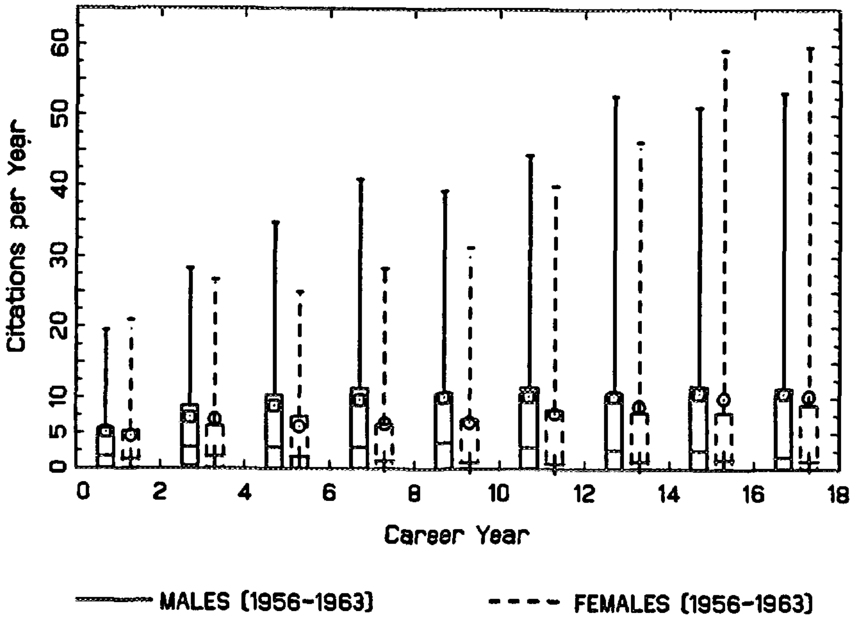


creasing steadily from the tenth to the seventeenth years. By year seventeen the average paper by a female is cited 1.5 times *more often* than the average article by a male.

Many processes could generate more citations of articles written by females. The obvious explanation is that the average article by a female is more useful and thus more often cited than the average article by a male. But the question remains, why is this so? How is it that females consistently publish less and, by most accounts, are in more marginal scientific positions than males yet receive more citations of the articles that they publish? Several possibilities exist. First, if males are more centrally located in science, they can be expected to have more students at the graduate and postgraduate level. To the extent that males collaborate on less frequently cited papers as a result of their mentoring obligations, those articles would decrease their average number of citations per paper. This may explain the steady decrease in the citations-per-article ratio over time, but it does not explain the sex differences in the ratios earlier in the career. Second, if females are in more marginal positions, they would not have the resources to publish as many papers. Female scientists may be compelled to make each article as important as possible, rather than saving some results for their next article. These suggestions are speculative. Detailed analyses beyond the scope of this article are necessary to fully answer this intriguing question.

Cole and Zuckerman (1984) suggest that sex differences in number of citations are due largely to sex differences in number of articles. The current results extend this idea. Differences in number of citations are *totally* the result of differences in number of articles. If females published at parity with males and maintained their level of citation per paper, they would have significantly more citations than males. This is an important finding, since it demonstrates that although female scientists may be in

FIGURE 5: Box Plots of Citations, by Career Year



marginal positions, their published work is not marginal—it is used and cited by others.

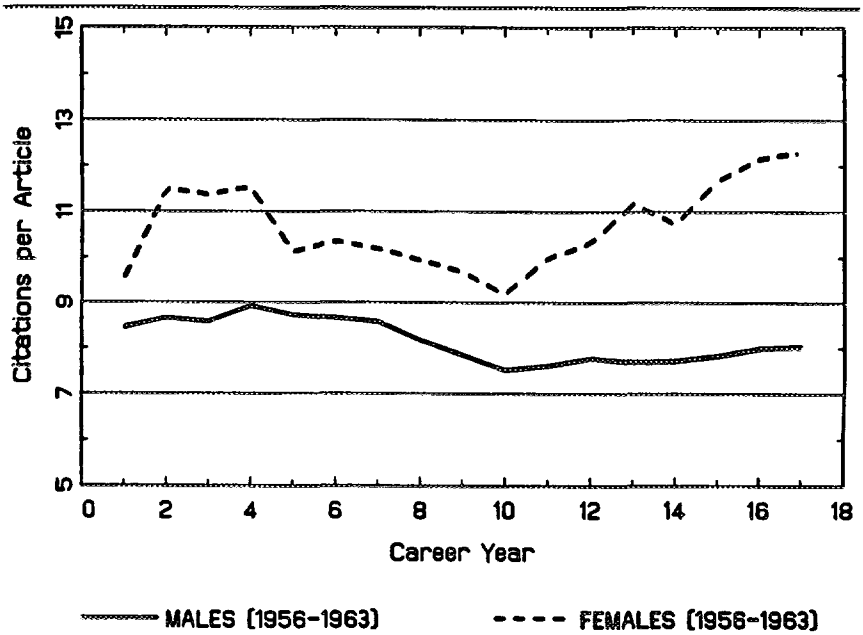
Conclusion

Sex differences in scientific productivity begin during graduate education and persist at least through the first seventeen years of the career. Understanding these differences begins with understanding differences in levels of publication, but it must go beyond a simple comparison of means. Over time, increasing numbers of males and females become nonpublishers, and the spread between the least and the most productive steadily increases. The lower rate of publication for females is due most importantly *to the greater proportion of females who* do not publish and to a lesser extent to the higher rate of publication of the most productive males. Perhaps most fundamentally, we must understand what differentiates publishers from nonpublishers.

It is plausible that the marginal positions disproportionately held by female scientists would drive them from a research career or would result in their writing trivial or unused papers, but this is not the case. While females publish less than males, there is no evidence that they are steadily pushed to the margins of science. While sex differences in publication increase over the first decade of the career, they diminish over the second decade. A significant proportion of females not only maintain their productivity but increase it, whereas the average male's productivity levels off. And, most significantly, the papers females publish are not relegated to obscurity. The average paper of a female scientist is cited more frequently than the average paper of the more prolific male scientist.

To what extent can the findings in this article be generalized to scientists in other fields and different cohorts? While a definitive answer is not possible, there are reasons to believe that the results should hold quite well. Most findings are consistent with those in the literature but go beyond them by providing additional detail. Other results that appear to differ can be explained by differences in the types of

FIGURE 6: Average Citations per Article, by Career Year



samples used. For example, the importance of distinguishing between publishers and nonpublishers was illustrated in several figures and reflects the differences that can be observed if a sample is restricted to successful or active scientists, rather than to a representative sample of all Ph.D.'s. The generalizability of the results is also indicated by recent work by Allison and Long (1987, 1990), which extends earlier research on male biochemists to consider scientists in chemistry, physics, math, and biology. Prior results based on biochemistry are generally corroborated.

Results for the 1950 cohort of females indicate that care must be taken in generalizing to periods before 1956. The 1950 cohort was different from later female cohorts in several key ways. Most importantly, the average number of publications for this cohort did not increase with time, as it did for other cohorts. While the specific reasons cannot be determined, it is clear that a greater percent of the 1950 cohort did not publish in a given year. One possibility is that changes in biochemistry resulted in earlier cohorts publishing less, regardless of sex. Alternatively, females in the 1950 cohort may less frequently be in positions where research is possible or required. For example, preliminary results suggest that a greater proportion of the 1950 cohort worked in the area of nutrition and home economics. An adequate answer requires detailed analysis of the work activities of this cohort, a task beyond the scope of this article. Overall, the differences between the 1950 cohort and later cohorts demonstrates the importance of history. Some processes appear similar, but others change with time. Accordingly, results of synthetic cohorts in which different Ph.D. cohorts are used to simulate different ages of a single cohort must be used with great caution.

This article has not provided an explanation of sex differences in productivity, but it has clarified what needs to be explained and where the foci of such analyses must be. Additional research is currently being conducted to understand the processes generating the sex differences in productivity shown here.

Notes

1. These are three-year counts. Thus, 55% collaborating in year one means that 55% of the students wrote at least one paper in collaboration with a mentor during career years zero, one, and two.

2. There are two basic ways to compute the average number of authors. First, the average number of authors per paper can be computed for each scientist, and these averages can be averaged across scientists. This approach gives a scientist with one publication the same impact on the group average as a scientist with a hundred publications. Second, the total number of authors for all articles in the sample can be divided by the total number of articles. This method gives each article an equal weight. The second method was used for the figures presented. In all cases, scientists without publications in a given year are not included for that year.

3. The evidence presented is for the average position of males across all articles compared to the average position of females across all articles. Given the similarity of males and females with regard to average number of authors, this is a reasonable comparison. Other analyses considered a measure of relative position (i.e., position/number of authors), which provided similar results. Relative position was not used because of the impact of single-authored papers on this measure.

4. The first letter of each last name was assigned a number from 1, for A, to 26, for Z. The average letter for females was 11.49 (between K and L), and the average letter for males was 11.65.

5. The mean citations per article are computed as the mean number of citations divided by the mean number of publications, which gives each article equal weight. Alternatively, the mean number of citations per paper could be computed for each sample member, and the mean of this measure across all cohort members computed. This approach gives each scientist an equal weight, thus disproportionately weighting the articles of those with few publications. Results for this measure are similar but are not reported.

References

Allison, Paul D. 1977. "The Reliability of Variables Measured as the Number of Events in an Interval of Time." Pp. 238-53 in *Sociological Methodology*, 1978, edited by Karl F. Schuessler. Jossey-Bass.

Allison, Paul D., and J. Scott Long, 1987. "Interuniversity Mobility of Academic Scientists." *American Sociological Review* 52:643-52.

----------. 1990. "Departmental Effects on Scientific Productivity." *American Sociological Review* 55:469-78.

Cole, Jonathan R., and Stephen Cole, 1973. *Social Stratification in Science*. University of Chicago Press.

Cole, Jonathan R., and Harriet Zuckerman. 1984. "The Productivity Puzzle." Pp. 217-58 in *Advances in Motivation and Achievement*, edited by Martin L. Maehr and Marjorie W. Steinkamp. JAI Press.

Garfield, Eugene. 1972. "Citation Analysis as a Tool in Journal Evaluation." *Science* 178:471-79.

Heffner, Alan G. 1979. "Authorship Recognition of Subordinates in Collaborative Research." *Social Studies of Science* 9:377-84.

Lindsey, Duncan. 1980. "Production and Citation Measures in the Sociology of Science: The Problem of Multiple Authorship." *Social Studies of Science* 10:145-62.

Long, J. Scott. 1990. "The Origins of Sex Differences in Science." *Social Forces* 68:1297-1316.

Long, J. Scott, and Robert McGinnis. 1985. "The Effects of the Mentor on the Academic Career." *Scientometrics* 7:255-80.

Price, Derek J. de Solla, and Donald deB, Beaver. 1966. "Collaboration in an Invisible College." *American Psychologist* 21:1011-18.

Reskin, Barbara F. 1979. "Academic Sponsorship and Scientists' Careers." *Sociology of Education* 52:129-46.

Zuckerman, Harriet. 1968. "Patterns of Name Ordering Among Authors of Scientific Papers: A Study of Social Symbolism and Its Ambiguity." *American Journal of Sociology* 74:276-91.

----------. 1977. *Scientific Elite: Nobel Laureates in the United States*. Free Press.