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Women in Mathematics: Motivating Factors For Doctorates in Academia Versus Professionals in the Actuarial Sciences

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Abstract

The topic under investigation is women in math-related careers and the motivating factors. Two careers, college professors and actuaries, were selected from the many math-related careers because both require advanced studies in mathematics. They also provide a contrast: one is in the business world while the other is in the world of academia.

The purpose of this research is to determine if the numbers of women in upper level mathematics and these two careers are increasing. To accomplish this we first analyze women's enrollment in mathematical programs from high school through graduate school from 1965-1995 in order to assess the impact of affirmative action. Then we compare and contrast performance levels for males and females on two standardized tests, National Assessment of Educational Progress Mathematics Test for age 17 and the Mathematics Section of the SAT. Next, the employment statistics for actuaries and women in academia are presented. The sources of the statistics are the National Science Foundation, American Mathematical Society, and the Society of Actuaries.

The second component of the research deals with what can be done to recruit more women into math-related careers by looking at the factors that encourage or dissuade women from this choice. Mathematical stereotypes, mathematical skill levels of women, female patterns of knowing, and social factors which influence academic and professional choices of women are investigated. Additional focus is given to summer math intervention programs since they are so successful in persuading women to continue with graduate studies in mathematics.

The research indicates, that although the gap on mathematical Associate Professor, Department of Mathematics and Statistics standardized tests between males and females is getting smaller and enrollment in high school and undergraduate mathematics is on par with the number of women in the general population, the number of women choosing math careers in academia and graduate studies in mathematics is much lower than the number of men and is increasing at a lower rate.

Research Question

What enrollment patterns are prevalent for women in college mathematics and how have these patterns changed in the last forty years? If women are choosing math-related careers- in particular, actuaries and women with Ph.D.s in mathematics in academia, what factors are motivating them? What factors do they have to overcome?

Statement of Methodology

This thesis paper will encompass both a quantitative review of the literature and qualitative research. The quantitative review focuses on enrollment patterns in mathematics classes and programs from high school to graduate school from 1965-1995. We also compare and contrast performance levels for males and females will be made using two standardized tests for high school students, the SAT and National Assessment of Educational Progress mathematics test for age 17. The final set of statistical data concerns employment rates for women in academia and women as actuaries. The purpose of this research is to examine the current statistics and to determine what trends are emerging. The statistics will be taken primarily from research done by the National Science Foundation, American Mathematical Society, University of Wisconsin-Madison and the Society of Actuaries.

The second type of methodology will be qualitative, a scholarly approach to investigating the factors that lead women to make the choice to enter these two fields. Books, journal articles and studies in the fields of mathematics and education will be used to explore the many factors that influence women to choose math-related careers. The idea behind this qualitative approach is to investigate why women choose math-related careers is to answer the question of why do women choose careers in mathematics. We ask if there are gender–related differences in mathematical problem solving and if so, how do these gender-related differences in problem-solving influence women when electing academic areas of study. Social factors to be researched include the effects of: childrearing on choice of career, stereotypes of mathematicians, both male and female; role of mentors; admissions practices and scholarships; and the politics of the job market (both hiring and promotion opportunities).

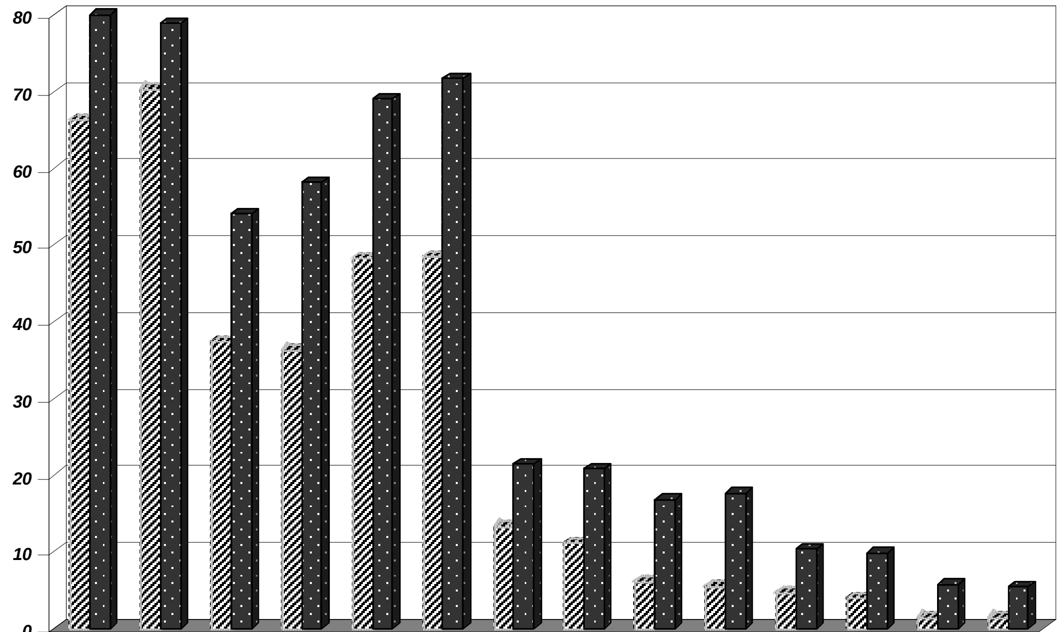
The preliminary research indicates that most women choose math-related careers primarily for the same two reasons as men: a love of mathematics and puzzle solving, and a mentor who encouraged them in their mathematical studies. However, women are still choosing math-related careers in lower numbers than men with a low rate of increase. This research will focus on what gender-specific factors contribute to the current trends for women in mathematics.

Results

The National Science Foundation tracks enrollment in seven mathematics courses in high school: Algebra I, Algebra II, Geometry, Trigonometry, Pre-Calculus, Calculus and AP Calculus. In 1982, there were a larger percentage of males enrolled than females in four of these courses (Algebra II, Trigonometry, Pre-Calculus, and Calculus) where AP Calculus has the same enrollment level for males and females and Geometry only has a .2 % difference in favor of females. In 1992, a larger percentage of males than females were enrolled in four of these courses (Algebra I, Trigonometry, Calculus and AP Calculus) and Pre-Calculus only had a .8% difference in favor of females. Three courses, Algebra I, Trigonometry and Calculus, experienced a narrowing of the gaps between enrollment for males and females and the remaining four courses experienced minimal percentage increases (.2% for Pre-Calculus, .3% for AP Calculus, 2.5% for Geometry, and 2.9% for Algebra II). Enrollment levels in high school mathematics classes (Chart 1) have significantly increased between 1982 and 1992 for females (with growth ranging from 12% to 286%). The conclusion is that the gap between male and female enrollment in these courses is diminishing. The National Science Foundation and National Institute for Science Education track gender proficiency trends on two standardized tests, National Assessment of Educational Progress Mathematics test for age 17 and the SAT. Between 1984 and 1994, college-bound females have scored consistently on average 50 points lower than college-bound males have on the mathematics component of the Scholastic Aptitude Test (National Science Foundation, 1996, p. 136). However on the National Assessment of Educational Progress Mathematics test for age 17, the gaps between scores by males and females from 1978 to 1992 (see Table 1) have been decreasing across all percentiles as the scores have been rising for females. Considering that enrollment in high school mathematics courses has been increasing significantly for females and that this enrollment pattern should have a positive impact on scores on standardized tests of mathematical ability, the positive trend experienced by females on the NAEP mathematics test more accurately reflects the expected increased proficiency in mathematics for high school females than does the SAT.

Chart 1

High School Enrollment in Mathematics Courses
A Comparison between 1982 and 1992 for Males and Females



	Algebra I Males	Algebra I Females	Algebra II Males	Algebra II Females	Geome-try Males	Geome-try Females	Trigono-metry Males	Trigono-metry Females	Pre Calculus Males	Pre Calculus Females	Calculus Males	Calculus Females	AP Calculus Males	AP Calculus Females
1982	66.4	70.4	37.5	36.3	48.3	48.5	13.3	11.2	6.1	5.5	4.7	4	1.4	1.4
1992	80	78.9	54	58.1	69	71.7	21.4	20.8	16.8	17.6	10.3	9.8	5.7	5.4

Adapted from *Women, minorities, and persons with disabilities in science and engineering: 1996* by National Science Foundation, 1996, September, 111.

Table 1

Average Scores by Percentile for NAEP Mathematics Test for Age 17

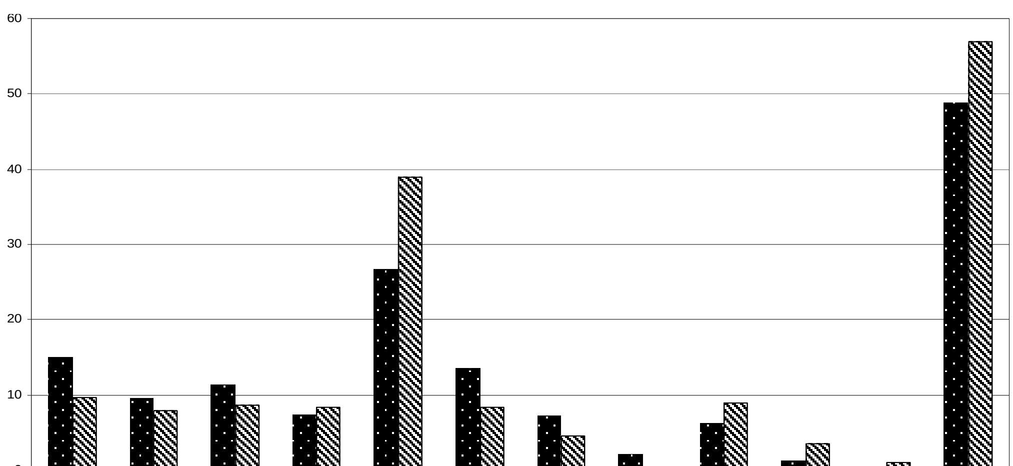
Percentile	5th	10th	25th	50th	75th	90th	95th
1977 Male	219.5	238.2	267.6	298.5	328.1	353.9	368.8
1977 Female	207.5	226.1	254.5	283.8	311.5	336.3	351.2
1986 Male	213.9	231.4	263.5	298.7	327.6	353.4	367
1986 Female	209.8	228.1	256.2	283.7	310.8	333.5	348.3
1992 Male	219	235.5	267.4	301.3	333.6	357.2	370.4
1992 Female	216.5	232.9	260.3	290.9	319.8	341.4	354.4

Adapted from *Women, minorities, and persons with disabilities in science and engineering: 1996* by National Science Foundation, 1996, September, 115.

The number of females earning Bachelor degrees in Science and Engineering and mathematics has increased[1], in large due to affirmative action in the late 1970's. "In 1975, females earned about one-quarter of the degrees in the natural sciences…By 1995, females earned…47 percent of the natural science degrees, 35 percent of mathematics." (National Science Foundation. 1998, p. 2-19) It is significant to note that the largest rate of growth occurred between 1975 and 1983 when the percentage jumped from 25% to 43.8%. The only degree program in Science and Engineering not to have experienced growth in female graduates is Computer Science which declined from 36.4% in 1983 to 28.3% in 1993 (National Science Foundation, 1996, p. 170). This is due in part to the increased educational funding for females through Affirmative Action in the late 1970's. It is interesting to note that the percentage of women earning undergraduate degrees in science and engineering degrees is almost equal to the percentage of women in the general population and the percentage of undergraduate degrees in mathematics by women is slightly lower. This a considerable increase experienced in the relatively short period of time of two decades.

Between 1966 and 1972, the percentage of Master degrees in science and engineering degrees had increased from 13.3% to 18.9% (females earned Bachelor degrees in all other fields at 42.2% and 47.4%, respectively). Again it is believed that due to increased educational funding to females by Affirmative Action, the percentage of women receiving a master's degree in science and engineering fields increased dramatically to 30.1%, and Master's degrees in mathematics being earned by females increased to 30.5% in 1983. The trend has continued upward so that in 1993, the percentages are 35.8% and 30.7%, respectively but the increase occurred at a much slower rate. The percentages of women earning Doctorate Degrees in Science and engineering are even lower: in 1960 the number of females earning doctorates in science and engineering fields was 8%, increasing to 11.1% in 1972. The percentages for doctorate degrees made the same dramatic increase as it did in the undergraduate and master's degrees, rising to 23.8% in science and engineering and 16.1% in mathematics in 1983. The increase between 1983 and 1993 has been more modest, 30.1% and 23% respectively (National Science Foundation, 1996, pp. 200-202). The percentage of graduate degrees in mathematics earned by females is substantially lower than percentage of females in the general population and lower than the percentage of undergraduate degrees earned by women in these areas. In analyzing doctoral degrees in the Mathematical Sciences, it is useful to see what field of thesis women selected. Women selected puzzle-solving and pattern recognition mathematics (Probability/ statistics/biostatistics, Algebra Number Theory, and Discrete Mathematics/Comb./Logic/Comp. Sci.) more often than men , 56.9% compared to 48.8%, (see Chart 2). This tendency will be discussed more fully when gender differences in mathematical learning styles are discussed (American Mathematical Society, Aug 2003, p. 3).

Chart 2 Field of thesis in Mathematical Sciences for 2001-02 Doctoral Recipients



	Algebra Number Theory	Real. Comp Func. &	Geometry/ Topology	Discr Math/ Combin/	Prob/Stat/ Biostat	Applied Math	Numerical Analysis/ Approx.	Lin/Nonlin Optim/ Control	Differ, Integral & Difference	Math Educ.	Other	Puzzle-Solving/ Pattern
% of Males	14.89	9.57	11.25	7.29	26.6	13.53	7.14	1.98	6.08	1.22	0.46	48.8
% of Females	9.66	7.93	8.62	8.28	38.96	8.28	4.48	0.34	8.97	3.45	1.03	56.9

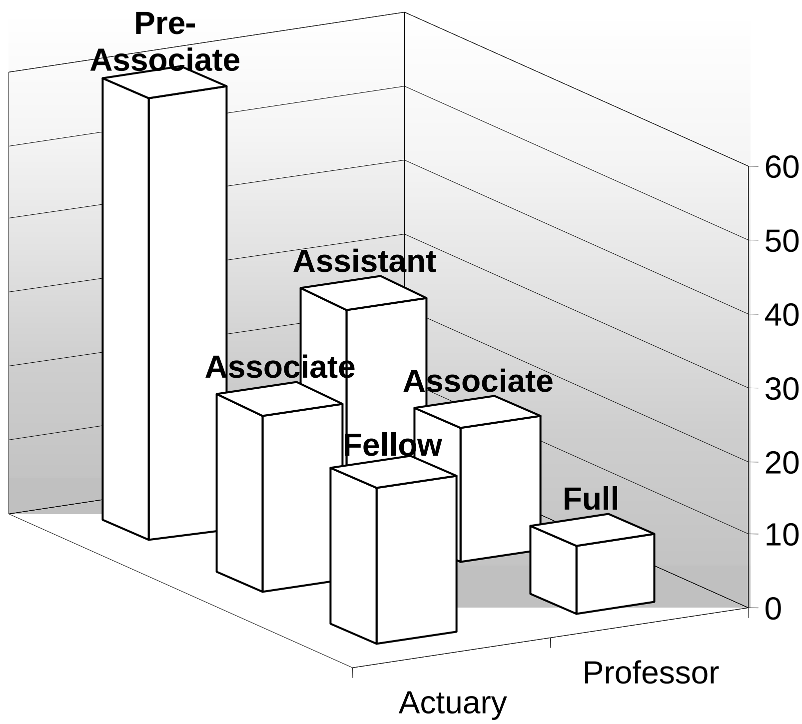
Adapted from American Mathematical Society. (Aug 2003). *Notices of the AMS, excerpts from 2002 first report* [Electronic version]. 3.

This is in contrast to trends concerning women in actuarial sciences. First, it is necessary to define the terms, pre-associate, associate and fellow. According to the Casualty Actuarial and Society of Actuaries, one of the two largest organizations for the accreditation of actuaries:

> Actuaries in the U.S. and Canada achieve professional status by passing a set of examinations prescribed by the Casualty Actuarial Society (CAS) or Society of Actuaries (SOA). Examinations are held twice each year in the Spring and Fall at various cities in the United States, Canada, and other countries around the world. Exams 1, 2, and 4 are jointly administered by the CAS and SOA.
>
> Many prospective actuaries begin taking exams while in college with the aid of self-study courses jointly offered by the CAS and SOA. Most achieve Associateship in three to five years. All students acquire a core set of knowledge from required courses before following the CAS or SOA career path. A student's selection to pursue the SOA or CAS career path is frequently influenced by personal interest, set of skills, and acceptance of a particular entry-level job.
>
> The Society of Actuaries offers required and elective self-study courses. Prospective actuaries must earn credits from several course exams to become an Associate. In the Casualty Actuarial Society, successful completion of Exams 1 through 7, and attendance at the CAS Course on Professionalism, satisfy the membership requirements as an Associate.
>
> After achieving Associateship status and usually after gaining a few years of work experience, most actuaries complete the Fellowship exams. SOA candidates choose one of five specialty tracks: group and health benefits, individual life and annuity, pensions, investments, or finance. Several required and elective courses make up each track. Under the 2000 exam system, Fellowship candidates will also fulfill 50 hours of Professional Development activities. These are very flexible study plans; allowing the candidate to choose form areas of personal interest and ways to gain that knowledge.
>
> To achieve Fellowship in the Casualty Actuarial Society, candidates must complete an additional two exams covering such topics as investments, financial analysis, advanced ratemaking, and individual risk rating plans. In summary, satisfactory completion of all nine exams is required for CAS Fellowship, the highest mark of distinction a CAS member can achieve.

According to the Society of Actuaries, 60% of the pre-associates are women compared to 27.4% of assistant professors. While only 24% of the associates are females, in 2003, half of the new associates were female. The percentage of fellows who are female is 21%, with 22% of the new fellows in 2004 being female. (Erin Research, Inc., 2002 and Society of actuaries, 2004) The percentage of women becoming actuaries is higher than the percentage of women entering careers in academia and they are advancing more quickly than women in academia. (Chart 3 highlights the differences.)

Chart 3 Comparison of Percentages of Women in Academia versus Professionals in Actuarial Sciences



Based on National Science Foundation. (1996, September). *Women, minorities, and persons with disabilities in science and engineering,* National Science Foundation. (1998). *Science and engineering indicators,* and Erin Research, Inc. (2002, October). *Member and candidate survey, 2002).*

Review of the Literature

The second part of the research deals with the factors that either encourage or dissuade women to choose math-related careers. These factors include sociological, societal and economic pressures which do not encourage careers in mathematics. One of the main sociological factors is the stereotype that mathematics is a male domain. Women not only have to deal with mathematics being male gendered but girls in America are often subjected to the idea that beauty and brains are cannot coexist. Hence, the image of the female mathematician is one of a geek, an outcast nerd.

There is also the myth of the mathematical career: that the mathematical career must be continuous and that most mathematical discoveries are made early in life. Child-bearing and child-rearing are at odds with this which delays their most significant contributions until later in life than men. Many young females react negatively to this and accept that one cannot have both a family and a mathematical career.

Because most women are social learners, they not only face the obstacle of overcoming the lack of females in the classroom but also the obstacle of using a separated learning method. Typically, women learn by collecting the ideas of others and by relating these ideas to their own knowledge; men usually are more impersonal and individualistic learners, relying on interactions with the teacher. Since mathematics is usually taught using lectures and not group settings, women are more at a disadvantage than men due to their preferred learning style. Their ways of knowing and mathematical reasoning patterns are often different from men and typically, mathematical curriculum is designed with male pattern problem solving methods in mind. Women generally rely on intuition and induction whereas most men prefer prepositional logic and deduction.

If they chose a mathematical career, women typically will obtain tenure at a much slower pace than their male counterparts. This is due in part as females in mathematics are expected to be mentors to other females, to correct the injustices of the past, and this can detract from time needed to do research and publish. While the overt discrimination against women in the math department is largely gone, subtle discriminatory factors are still there and women are not on equal footing with men in mathematics.

The motivating factor in this research, gender, has been studied by numerous authors. Rees, Amy, Jacobson and Weistrop (2000) cited Londa Schielberger (1999) who distinguished gender from sex: "gender is indicative of the 'multidimensional and changing understanding of what it means to be a man or a woman within a particular social setting.' Sex, on the other hand, refers to the biology of an individual…women as a group have been undervalued in science [mathematics], the culture of science [mathematics] has been gendered masculine" (parentheses inserted by author). Due to societal and gender pressures, women are considerably more likely than men to drop out of the mathematical track in education (Vetter, 1988, p. 15).

Mathematics is viewed as a male domain and this gender orientation dissuades girls from pursuing mathematical course of study. One of the reasons given by Kenschaft (1987) is there is a widespread belief in America that "women…cannot learn mathematics as easily as…males" and this has become a self-perpetuating myth (p. 170). Hence, women rationalize their deficiencies in mathematics instead of persisting and mastering its concepts. "Women and girls, in particular, are prone to believing messages that relay that mathematics is a difficult subject and that each person inherited a mathematics gene at birth. For decades, cultural scripts have dictated that boys are inherently better in mathematics and science than girls...the pattern of differences in mathematics achievement strongly suggest the influence of sociocultural factors" (Anderson, 2001, p. 27). Also, girls accept more readily than boys gender roles imposed by society and therefore, are more like to be dissuaded from mathematics because of the "general view by society that mathematics is a male domain" (Spence, 1990, p. 26).

Women must deal with issues concerning self-image. As Anderson (p. 20) noted:

> Women are informed at an early age that intelligence and beauty are two separate entities…beauty has a feminine overtone whereas intelligence is relegated to a masculine domain. This cultural notion is often reflected in the areas of mathematics, science, and technology which are highly regarded fields that attract bright and rational people. In these fields, men still outnumber women…Our culture continues to perpetuate the myth that women are deemed valuable and worthwhile based on their appearance.

Women in mathematics are often seen as boring nerds, social outcasts, and loners (Campbell, p. 9, Haimo, p. 7). As one female mathematician expressed it, "But I always wanted them (the boys) to say, I wished they would say I was beautiful…For some reason, intelligence to me. It wasn't that it didn't have feminine overtones …I wanted something else." (Anderson, p. 19). Boys in mathematics often receive the same teasing about being a math nerd but this teasing negatively affects teenage girls more than it does teenage boys. Add to social pressure outside the math class is the fact that boys in math classes often give the girls a hard time by constantly telling the girls that math–related careers are not a female profession (Coyle, p. 7). The idea expressed is mathematics is a man's world and boys will not be interested in girls who are too good in math (Anderson, p. 27).

One group of students after being introduced to a group of women scientists both in a historical context and as guest speakers “were amazed that eminent women scientists looked like people the students knew”. When the students were able to see that women scientist were normal–looking people, they then went on to ask questions like: “What’s a university and who can go? What does research mean?” (Plucker, p. 212). One must really question why so many biographies of women mathematicians comment on their looks—is it really important to know that Emmy Noether was short and squat and physically unattractive and that Emilie du Chatlet was considered a plain child who later turned into a beauty (Kelley, p. 592, 595). Instead, biographies should be presented as a balance between the positive experiences and difficulties faced by women mathematicians (Plucker, p. 213). “Few formal barriers remain to the study of mathematics by girls and women but mathematics still remain an ‘unfeminine’ image” (Spence, p. 27). It makes the point that Hilbert once made while defending Emmy Noether’s appointment as a professor of mathematics (a paying position she never received in Germany), “After all, we are a university, not a bathing establishment.” Introducing more biographies concerning women mathematicians in math curriculum can alleviate the problem of self-image many girls in mathematics have.

Mathematics is also viewed as a “white” domain and this further reduces the number of women who pursue mathematical careers. Although this research is based on gender, it is noteworthy that by 1984, only twenty-six black women had earned doctorates in mathematics (Kenschaft, p. 188). In 2002, no American Indian, Alaska Native, Native Hawaiian or Pacific Islander female received a doctorate degree in mathematics and there were only eight Hispanic and eight black female doctorate recipients (American Mathematical Society, p. 6). Vivienne Malone Mayes, one of the first black women to earn a doctorate in mathematics said concerning her doctoral experience at the University of Texas, “’I was the only black and the only woman. For nine weeks, 30 or 40 white men ignored me completely…My mathematical isolation was complete” (Kenschaft, p. 188-89). Kenschaft further notes that “black children (are) exposed to less rigorous mathematics training...and their teacher’s expectations (are) lower. Because statistically their parents have received an inferior mathematical education, their homes are not brimming with mathematical enticements as those of whites…they are not even told about the existence of convincing role models that do exist” (p. 170). By alienating black females from mathematics, the percentage of women in mathematics, as compared to the percentage of women in the general population, is further lowered. Harding also recognized another aspect concerning the culture of science (and mathematics): “adding more women to science, without changing science-as-is, positions women within a system highly stratified by class, race and gender and may have the effect of strengthening race and class divisions between women” (Rees, et. al., p.316). Women are further segregated by class and race in mathematics. The percentage of women of color is lower than the percentage of white women in mathematics and both are lower than the percentage of men in mathematics.

Another reason the percentage of women receiving Ph.D.s in mathematics is lower than the percentage of women in the general population is that “the number of natural sciences and engineering students (and this includes mathematics) students with Ph.D.s earned by Americans has fallen for a decade…fields with the highest foreign component among the T(eaching) A(ssitants) and faculty are also those with the fewest women faculty” (Vetter, pp.4, 6). Because there are more foreign men than foreign women obtaining Ph.D.s in mathematics, the percentage of women obtaining Ph.D.s in mathematics is further lowered.

Also, females are more likely to develop a fear of mathematics than males.

While "tolerating some level of anxiety in doing mathematics is probably a good thing for mathematical creativity" (Blum, 1997, p.4), females express less enthusiasm for college math than males. As one female stated, "'I have spent a lot of time in the last few years wondering if I could do mathematics. It did not used to be that way" (Adhikari, Givant, and Nolan, 1997, p. 22). This lack of confidence in mathematical ability expressed by undergraduate women is significant because research has shown women are not as likely as men to continue in mathematics and other male domains when "their judgments of personal competence are low…women and men have different sex-typed experiences in childhood which limit women's exposure to the sources of information necessary to develop strong self-efficacy perceptions in traditional male-dominated careers such as mathematics" (Coyle, 2001, p. 3).

The reason most often given by female undergraduates for not continuing with graduate studies in mathematics is the perception that they lack the ability to succeed in graduate mathematics programs, despite similar GPA and SAT scores (Adhikari, 1997, p. 98). Brew noted that a woman has a greater fear than a man does of being ridiculed when she perceives her inability to say what she does not understand. This fear often leads to the fact that discussions in mathematics classes are usually dominated by males (Adhakari, 1997, p. 97).

Women's career expectations in mathematics are also lower than men even when they have similar abilities. Women are less likely than males to respond they are good at mathematics when asked why they choose mathematics (Adhikari, 1997, p.17, 19). This causes a larger percentage of females than males to drop out of a track in mathematics.

There is conflicting evidence on the effect of the belief that mathematics is objective and absolute is a stumbling block for women. While women express a higher reliance on rules and procedures than do men, the societal perception that mathematics is absolute and infallible dissuades older women who are returning to study mathematics. Older women, in particular, reject absolute thinking and lean more toward decision making in context (Brew, 1999, p. 1-2). Because research is a situation that involves taking risks and being comfortable in an unstable, unknown situation, women are less likely to pursue mathematical research than men. Women are much "happier with a predictable stable situation" (Anderson, 2001, p. 28).

Older women are also less comfortable with the belief that mathematics is infallible than younger women. Younger women are not only are more comfortable with this belief than older women but they are also more comfortable with it than men and it is one of the major reasons they give for studying mathematics. Yet among undergraduates who do decide to study mathematics, women are more likely than men to say that their reason for liking mathematics is the absolute truth-right/wrong nature of the discipline (Becker, 1996, p. 21).

Gender differences also exist in mathematical reasoning. Men use logic and deduction, preferring prepositional logic to validate arguments and are suspicious of what feels right. Women, on the other hand, rely on intuition and induction, tending to focus on context and other people's knowledge and shared experiences. Women use a receiving pattern of learning, one that typically involves listening and recording. Most men prefer interaction with the instructor. While many women are interpersonal (collecting others' ideas) and interindividual (focusing on thinking for themselves while engaging the view as others), men are more impersonal (individually centered) and individual learners. These are gender-related patterns in which the traditional way of teaching mathematics has not taken into account. Since mathematics has been traditionally taught to conform to separate knowing (Becker, p 20-24), the way in which mathematics is generally taught is not the way that females learn best (induction).

Women also have a preference for rational learning in that they need to show relevance of mathematics to everyday life more than men: “Women learn from within, exploring structural connections rather than mastering from without through formulaic applications to preexisting applications to preexisting tasks” (Schimmittau, p. 49). Girls, more than boys, “like to live in a world that makes sense” and unless they can make connections between mathematics and the world in which they live, they will abandon its study. Women value personal experiences more than men and they learn best in visual activities. As one woman returning to study mathematics said, “We did fraction additions and subtractions, using these fraction circles you call them and at the end of the week, I am the best in fractions, I topped the test…That’s what they were talking about, they weren’t pulling numbers out of their bums and putting them on the board” (Brew, p.1-2, 12). Hence, male-modeled learning is perpetuated as very few hands-on mathematical demonstrations are used in college classes.

Mathematics is often a solitary, not a social, thing and this is uncomfortable for most women who are indoctrinated to be social beings, not independent thinkers (Anderson, p. 28). Women are social learners, preferring to learn in groups (Bozeman, p. 89); they favor connectedness over separateness (Piirto, p. 146). This style of learning is not often used in mathematics classes. “Mathematics tends to have features that are traditionally ascribed to males—competition, isolation, independence, aggressiveness, hierarchy, and long hours that exclude family” (Anderson, p. 281). When questioned why they liked mathematics, males gave reasons that did not involve relationships. Girls expressed the reason they were drawn to mathematics was “their love for mathematics…Love of mathematics originated in its beauty. Neat, beautiful and interesting” (Anderson, p. 22). “The way in which they (females) learn mathematics is important to them. The process matters” (Adhikari, p. 21-22).

This is evidenced by a study by Handley. Handley compared two groups of women who were planning on careers in mathematically oriented fields. The groups were divided into teachers and non-teachers. Handley found that the non-teachers developed their interest in mathematics earlier than the teachers. The teachers were more people-oriented. The non-teachers were more idea-motivated and gravitated toward factors associated with mathematics like books, experiments and demonstrations and independent studies. Handley also noted that the non-teachers “scored significantly higher on both creativity and independence” than the teachers.

Also, women who remain in mathematics try not to be different from men in mathematics and girls are often encouraged to adapt male norms in mathematics (Brew, p. 1). Hence, many women learn to assimilate in male gendered mathematics. More research needs to be done to document the extent women will make adjustments to fit in—how much will they compromise their goals, beliefs, values and gender in order to fit in or survive in the male dominated world of mathematics (Anderson, p. 25).

In addition, teachers often treat boys differently from girls in mathematics classes. “Teachers generally allow the boys more freedom to deviate from the rules and algorithms and to discover alternative solutions to problems, whereas they require the girls to follow the rules more closely. Teachers treat gifted female students more negatively than male gifted students…counselors discourage girls from pursuing mathematics” ((Fabricant, p. 152) in a reaction to Affirmative Action, some mathematics professors “are very careful not to over advise their female students, be over supportive of the female students. They are afraid that would look like they are being sort of gender centric. What ends up happening is that the department seems to leave you out in the cold” (Anderson, p. 24).

Another problem is that women professors are expected to donate time to mentor other females. Mentoring is often dependent on soft money and volunteer efforts. The problem comes in that mentoring takes time away from research and publication. Universities are expecting female professors to "remedy the historical shortcoming of the academy by bearing the burden of creating a welcoming environment for themselves" but in so doing, mentoring exacerbates "the national problem of retaining and promoting women" (Rees, p. 328). This is one of the reasons it takes women longer to obtain tenure in the mathematics.

Another factor that dissuades females from mathematics is the fact that they are often one of the relatively few females in math class (Blum, p. 5) and this trend continues into professional lives of women mathematicians. "When the number of girls in nonrequired advanced mathematics courses becomes very small, the remaining girls tend to drop out" (Fabricant, p. 152). These feelings of isolation continue to dissuade women as they progress through their mathematical careers. As Rees and other noted, "the single most important indicator or predicator in a woman's is the proportion of women in her field" (Rees, p. 35). The sense of loneliness that many females experience in math classes is a major cause for women leaving mathematics. "There are so few women doing it…People are less used to that so they don't make it easy for you, so it's like you have to make more of a push" (Anderson, p. 24).

Women in mathematics often have to defend their academic credibility. "Up until the past two or so decades women with an interest and proficiency in mathematics were not considered creditable and were largely ignored" (Haimo, p. 7). The mathematical community has often made a distinction between interpreters and "true" mathematicians, with women often being classified as the former (Kunoff, p. 171). Perhaps female mathematicians still question their mathematical abilities because they feel as Mary Somerville, one of the greatest of all mathematicians, felt—"I have perseverance and intelligence but not genius. That spark from heaven is not granted to the (female) sex" (Spence, p. 26). Women are often half of a husband and wife team and their creditability is often diminished. "In a positive sense, living married to a known male mathematician put the woman in the mathematical network." William Young once wrote to his wife, Grace Chisholm Young, "the fact is our papers ought to be published under our joint names but if this were done neither of us would get the benefit of it. Mine the laurels now and the knowledge. Yours the knowledge only…This is my programme. At present you can't undertake a public career. You have your children" (Kunoff, p. 171-175).

At math conferences, there are very few women. As one female mathematician stated, "I am so used to it that I probably would feel strange if there were a room full of women" (Anderson, p. 25). There has never been a black woman in mathematics at the Princeton Institute for Advanced Studies (Kenschaft, p. 179). Very few women have been asked to speak as keynote speakers at the national American Mathematical Society meeting which has been held since 1888. Only Anna Pell Wheeler in 1927, Julia Robinson in 1980, and Karen Uhlenbeck in 1985 have been invited. Only in 1993 were women hired at research institutions in a slightly higher percentage than the rate at which females receive Ph.D.s. This trend has not continued. One and a half pages of the twenty-four page list of invited speakers to the Mathematical Association of America and AMS since 1967 contain women with most having been invited since 1990. Although the American Mathematical Society, American Statistical Association, and Society for Industrial and Applied Mathematics (SIAM) currently have female presidents-elect (Kunoff, p. 176-77), isolation and creditability are issues that affect women more negatively than men in mathematics.

Last, women are often dissuaded from mathematics for socioeconomic reasons. "Women often deal not only with the difficulties inherent in the subject but with the problems caused by studying in such an environment" (Adhikari, p.97). Family life and child-bearing choices can sometimes dissuade women from mathematics. “The mathematical life course” is one in which mathematical talent is recognized and nurtured early in life. Ratcliff goes on to say,

> The future mathematician charts a single-minded course to an elite college, graduate school, and postdoctoral position. His best research is done when he is young, and there are no interruptions to the course. In contrast most of the women interviewed by Murray, had children and experience significant interruptions to their education and careers. They had primary responsibility for the care of the home and family during the years when, according to conventional wisdom, they should be single-mindedly pursuing mathematics…felt they did their best work in mid-life…Researchers all married and had while establishing their mathematical careers (p.210).
>
> Many women feel creativity must be manifested early in life and, therefore, they face the alternative of having families or concentrating on their professional growth (Haimo, p. 7). Piirto noted that
>
> > the necessity to achieve early and the necessity for commitment and intensity in pursuing a career that calls for creativity, may work against women. Females have different career and productivity patterns. Females, because of reproductive and family necessity may peak later than males and may begin their career productivity later. It might then be too late for genuine eminence in the field. The bind of delaying having children, or having children early and not being able to single-mindedly create seems to be the crux of the problem for many creative women (p. 146).

In 1921, fewer than 12% of the female mathematicians were married. Many were forced to remain unmarried in order to keep their grants or jobs (Kunoff, p. 175). As Mary Somerville noted, “A man can always command his time under the plea of business, a woman is not allowed any such excuse” (Spence, p. 27).

Women also have to deal with the “two-body” problem—her career is often not as important as that of her husband. Women end up holding a series of positions as they are moved around the country because the husband’s career takes priority of that of the wife. “Some of the most important stages in the establishment of an academic career (such as finding permanent position and gaining tenure) occur exactly at the same time that couples are finding a home and raising children” (Ratcliff, p. 211). Also, universities historically have seen women as a “bad investment.” “Women just get married, have children, and never have careers, the university (Massachusetts Institute of Technology in this case) did not want to waste their scholarship dollars” (Ratcliff, p. 210).

Some women drop track in mathematics because they are unable to cope with the demands of full time study with children (Brew, p. 6). Often the reasons women give for abandoning mathematics are social: being the only woman in advanced mathematics classes, being a mathematician and raising a family are not compatible (Friedman., p. 250, 252). By inviting contemporary mathematicians to speak with young females and assigning women mathematicians to research outside of class, girls can see that being a mathematician and raising a family are possible. It can give girls insights in to understanding the experiences of female mathematicians, both in a mathematical and non-mathematical way (Anderson, p. 7). These sorts of experiences can give girls a realistic view of what female mathematicians do and that it is possible to have a career and a family.

The three most common features for female success in mathematics (and this applies to Hypatia in Ancient Greece through contemporary female mathematicians) are a supportive family background, early exposure to significant mathematics and female role models in mathematics (Fabricant, p. 150). One woman in academia expressed her feelings concerning her family: they enabled her not to feel embarrassed about the fact that she enjoyed mathematics. Another told a story about her father's role in her decision to pursue mathematics:

> I was trying to do my homework and I said, "I just can't do it, I just can't do it. My teacher says it's okay because I am a girl." He (her father) just got furious. He made me sit down with him for several nights and just work problems. He even told me, "Don't think like that," that I can do anything that I wanted to do. I think that was a real turning point. I think because I listened to my parents I ended up in the field. (Anderson, p. 15, 23)

Because of their social nature, girls rely more upon people than skill in pursuing math-related careers (Coyle, p. 8). Women credit a mentor for fostering their success in mathematics (Ratcliff, p. 209; Kelley, p. 592; Adhikari, p.21; Burns, p. 95; Fowler, p. 104; Coyle, p .6). "Women report being in need of more persuasion from at least one person, usually a teacher, to pursue a graduate degree in mathematics" (Coyle, p. 3). Unless more women earn graduate degrees in mathematics, the proportions of women in academia will not increase an without more female role models and faculty, women students will still experience isolation and thereby, dissuaded from entering mathematics (Vetter, p. 6). Hence, mathematics as a male domain will continue to be self-perpetuating.

Discussion

The large increase of female mathematicians in the 1980's was because, for the first time, girls were not consciously being counseled out of mathematics. There has been a "growing realization by contemporary mathematicians that women had difficulty becoming part of the mainstream of mathematics" (Kunoff, p. 171). Gone were the ideas of the 1970's and earlier when girls were told, "Why spoil a good GPA with a B or C in math?" Female mathematicians were also becoming more numerous and female mathematicians began to be involved in providing the tools for success in mathematics for girls. As Blum noted, "The best way to get people to overcome their avoidance of mathematics was to provide successful experience in math sciences" (p. 3-4).

While women's groups in the 1970's talked about negative experiences in mathematics, effective programs have been difficult to create much less fund. It has been almost thirty years since Affirmative Action and considering there is a seven to ten year gap between entering a Bachelor's degree and obtaining a Ph.D., there has been more than enough time for the percentage of women obtaining Ph.D.s in mathematics to rise to the percentage of women in the general population. This even takes into account the "drop in quality of pre-college education, particularly in math and sciences that occurred during the 1970's for a substantial fraction of the nation's youth" (Vetter, p. 1). Not only has it not increased substantially (less than 25% compared to 51%), the number of female Ph.D.s has stabilized and has a very low rate of increase.

In high school and undergraduate studies, the percentage of women in mathematics is on par with the percentage of women in the general population. The gap between achievement scores for boys and girls on the National Assessment of Educational Progress at 17 is closing while the SAT scores on the mathematics portion have remained the same with a 50 point gap (this despite an increase in enrollment for females in upper-level high school mathematics classes). For this reason, it is unfortunate that the SAT is the standardized test most frequently used by colleges to evaluate mathematical ability of college-bound students. In actuarial sciences, the percentages are going up across all levels, with the exception of Fellow. Once again, there is a time lapse between becoming an Associate and a Fellow and given that 50% of the total number of actuaries achieving

Associate were women, eventually the percentage of women achieving Fellow will begin to rise. Without a rise in the percentage of women obtaining Ph.D.s, the percentage of women in academia cannot rise.

There are many ways to recruit more women into mathematics and into graduate studies in mathematics. It has been suggested that one way to deal the view of mathematics as being male domain is to have same-sex classes. The research shows that girls do achieve better in same-sex classes and they develop a more positive attitude toward mathematics. Girls in these situations were also more likely to "continue their mathematical education than in coeducational classes." This is due in part to the fact that in coeducational math classes, "girls tend to assume the passive role of recorder and boys the active role of experimenter" (Fabricant, p.152). Research also has shown that women can improve their self-efficacy in mathematics by occasionally participating in same-sex environments such as summer intervention programs in which female undergraduates are exposed to challenging mathematical projects and networking experiences with women in mathematical fields. Women in these programs experience growth in self-esteem and mathematical maturity and see mathematics as a creative process. (Gupta, p. 105; Fabricant, p. 153; Robinson, p. 113-116; Bozeman, p. 89; Haunsberger, p. 109). Same-sex programs allow females to see that other women share the same feelings about mathematics (isolation, concerns about having a family, worries about mathematical ability, etc) and this allows them to develop the self-confidence and perseverance to continue in graduate mathematics studies.

However, while it can be very helpful at critical points in a woman's education to have a mathematics taught in same-sex settings, women cannot afford to be segregated because women need to be "exposed to male mathematicians so that both learn early how their counterparts deal with similar problems and how they think" (Haimo, p. 10). Women need "a chance to do and learn math in ways that most successful male mathematicians take for granted" and this can only be achieved by working together on mathematics problems (Blum, p.4). Women cannot afford to be completely isolated from male mathematicians.

Curriculum in mathematics classes "should demonstrate applications of mathematics to fields currently of interest to women, and textbooks should include biographies of female mathematicians" (Fabricant, p. 153). There are successful programs for recruiting women into mathematics in the high school such as EQUALS (University of California at Berkeley), Futures Unlimited Project (Rutgers University) and Keep Your Options Open, all of which use female role models to humanize mathematics. Career education can also demonstrate to girls that mathematics can be fun and useful and can instill confidence that girls can do and enjoy mathematics (Fabricant, p. 153). Girls, more than boys, need information on the importance of mathematics to their futures and career development. They need positive hands-on experience. To alleviate the feelings of isolation, young female mathematicians need to become part of networks with other female mathematicians (Blum, p. 4, 5). "Female underrepresentations in quantitative curriculum should be addressed, regardless of whether or not the introduction of these representations significantly increase female achievement" (Plucker, p. 210). Bernstein listed a website for a list of female mathematicians: www.scottlan.edu/lriddle/women/alpha.htm as well as another for all mathematicians www-groups.dcs-and.ac.uk/~history/Indexes. In addition, teachers need to pay equal attention to boys and girls and make certain there are an equal number of girl-lead groups.

At the college level, summer programs in mathematics for women and Research Experiences for Undergraduates (REU) should be continued. Programs such as Women in Science and Engineering (WISE) at University of Nevada at Las Vegas should be funded. WISE is a program which gave graduate student support and small summer research enhancement grant as well as provided academic recognition for women in mathematics, critiquing of drafts of National Science Foundation proposals, among other networking and mentoring services. Professional organizations should continue the trend toward including more mathematical papers and research by women.

There are women in the midst of the mathematics departments and their numbers are substantial in the high school and undergraduate classes. As long as continued attention is given to recruiting them into graduate studies, their numbers in academia will continue to rise. As Campbell noted, we can no longer afford to dissuade women from pursuing Ph.D.s in mathematics—we are not going to have the trained mathematicians to meet our needs and while most of the factors which dissuade women from mathematics are social in nature, “Few sex-related cognitive differences exist in mathematics achievement, suggesting that women are equally capable of achieving in mathematics as compared to men” (Anderson, p. 27). By addressing curriculum and support systems for women in mathematics, the trend set in undergraduate mathematics course can be duplicated in the graduate schools which will positively affect the number of women in academia.

While women in actuarial sciences experience many of the same factors which dissuade women in academia from careers in mathematics (mathematics as a male domain and problems of self-image concerning beauty and race), they are better able to cope with other issues. Women in actuarial sciences usually only obtain a Bachelor’s degree in mathematics and thus the actuarial sciences avoid the dramatic decline in the percentage of women experienced by academia due to the percentage of women in graduate mathematics programs.

Because a higher percentage of women are entering actuarial sciences than careers in academia in mathematics, the proportion of women in the field is increasing across all levels of actuarial sciences. (See chart 3). Because the percentage of female Associates for the COA is 50% compared to 31% of the female Master’s graduates in mathematical science, the percentage of female Fellows will continue to be larger than the percentage of female doctorate recipients in mathematical sciences (and subsequently the number of professionals in academia in the mathematical sciences). Generally, women in actuarial sciences are less isolated from other women than women in academia.

Women in actuarial sciences experience less challenges to their credibility as mathematicians than women in academia. Passing actuarial exams and advancing toward the ranks of Associate (seven exams) and Fellow (two more exams for CAS Fellow or 50 hours of Professional Development activities for SOA Fellow) does not involve subjective judgment but is completely objective. For women in academia, obtaining tenure has a more personal and subjective nature as the candidate is judged by peers (predominantly male) as to whether or not she is “worthy” for tenure or promotion. Most women prefer predictable, stable situations and since progression in actuarial sciences is less subjective and risky than graduate studies and tenure, the percentage of women in actuarial sciences is higher at all levels than professionals in academia.

The course of study for actuaries is more flexible. The actuary may select from many different career development tracks and study programs and she can be more flexible in the amount of time she takes to progress through the stages of actuarial sciences. Most actuaries obtain the rank of Associate in three to five years and obtaining the rank of Fellow is a life-time goal for most. If she chooses to stop or pause before obtaining the next rank, there is no penalty unlike women in academia; the female actuary has enough education to proceed with her career. At each level of academia, whether it be the Bachelor’s or Master’s or Ph.D., the student goes back to entry level. If she stops during her graduate studies before obtaining a Ph.D., the female mathematician does not have enough education to pursue a true career in academia. Female actuaries have more time to deal with the demands of study and raising children than women in academia who generally pursue their mathematical studies full-time for seven to ten years. Consequently, women in academia have less flexibility and time to have a family and deal with the demands of family life than the female actuary.

Women generally need to see the relevance of mathematics to the real world and actuarial sciences satisfies this need since it is a career based on mathematical models used to predict the probability of an event. Probability and statistics is the number one choice for field of thesis for women in mathematical sciences.

Women in mathematics sometimes have a tendency to mimic male-gendered patterns in mathematical reasoning. As noted in Handley's study, female mathematicians who are not considering careers in academia tend to be like males and relate to the things of mathematics, such as books, experiments, demonstrations and independent studies. A career in actuarial sciences has all these features. Most actuaries study independently at their own pace and their work involves demonstrations of mathematical models and experiments.

The business world is also more likely to encourage the inclusion of women than academia because it cannot afford to isolate a large percentage of the population. Another factor which lures women out of academia and into business fields such as actuarial science is money. Given that there is a shortage of mathematicians, the business is usually willing and able to pay more for mathematicians than academia. It is an accepted tenet of economics that price is a function of demand and supply. The business world has the means to hire mathematicians at a higher rate of entry pay and to increase the salaries at a greater rate than academia. As Brew noted, women need to see that mathematics is an economically viable career choice and actuary has been ranked the number one job in America for several years. Actuarial science is a very lucrative field, with starting salaries for women with a Bachelor's degree in mathematics and having passed one or two actuarial exams being around forty-five thousand per annum plus benefits. Many female mathematicians with a Ph.D. earn near the same amounts in academia. Hence financial rewards and benefits, as well as other factors, lure women out of academia and into business fields such as actuarial science.

The increase of female mathematicians in the 1980's should not be squandered. Women can and do enjoy mathematics. Despite our living in a new millennium, mentoring and financial rewards to keep women in mathematics are needed as much today as they were in previous years. We just need to make certain that the women of tomorrow who walk into the upper-level math classes with a love of mathematics stay in greater numbers than those who have gone before them.

Notes

[1] Prior to the 1980's, the National Science Foundation did not separate the data on mathematics degrees from the totals for degrees in science and engineering.

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