2011

Women in Mathematics: An Historical Account of Women's Experiences and Achievement

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WOMEN IN MATHEMATICS: AN HISTORICAL ACCOUNT OF WOMEN'S EXPERIENCES AND ACHIEVEMENT

SUBMITTED TO

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AND

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FOR

SENIOR THESIS

SPRING/2011
APRIL 25, 2011

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Abstract

For a long time, women have struggled to gain complete acceptance in the mathematics field. The purpose of this paper is to explore the history of women in the field of mathematics, the impact and experiences of current female mathematicians, and the common trends for women in the mathematics field, through literature review and personal interviews. This paper looks at the lives of four famous female mathematicians, as well as female mathematicians in the Claremont Colleges who were interviewed for this paper. Specifically this paper examines the discrimination they faced and how they overcame this discrimination, as well as the contributions they have made to the mathematics field. In addition, studies about the effects of gender on mathematics achievement were explored. This paper tries to bring the conclusions of these studies together to present arguments from different perspectives. It also recognizes trends and changes in favor of women in the mathematics field in recent years. In spite of the contributions made by women and the improvements that have come about for women in the field, including the increased number of doctoral recipients, women still face challenges in gaining complete acceptance. Continued change can occur through mentoring and encouraging young women to pursue careers in the mathematics field.

A History of Women in Mathematics

For years, women in the mathematics field have been overlooked, underappreciated and harshly judged based on their gender. Mathematics is seen as a male-dominated field and it has been an uphill battle for women trying to break into the field. Despite this, there have been several women throughout history who have made significant contributions to and impacts in the field of mathematics. Four women whose journeys have stood out in history and who have risen above and beyond the expectations set out for them are Hypatia, Emmy Noether, Sofia Kovalevskaya, and Mary Ellen Rudin.

Hypatia is recognized as the first woman to have a significant impact in the field of mathematics, and some have referred to her as the "mother of mathematics" (Koch 96). She was born in the fourth century, the exact date unknown, in Alexandria, Egypt, one of the centers of mathematical thought at the time (Koch 94). Her father Theon was a mathematician and a philosopher. Theon raised Hypatia with an emphasis on education, but he wanted to make sure she was strong in all areas, especially the physical and intellectual (Koch 94). She was raised with the idea that she could do anything she wanted, which was very rare for women, especially during that time (Koch 94). She studied all areas of thought, but she flourished the most in mathematics, science and philosophy. Eventually she exceeded her father's knowledge, so he sent her to study in Athens, the mathematics center of the world (Koch 94). When she completed her studies in Athens, she traveled around Europe for about ten years.

Not only was Hypatia an excellent student and researcher, but she excelled in teaching as well. When she returned to Egypt, she was asked to teach at the University of

Alexandria (Koch 94-95). Her favorite subject to teach was algebra, but it was a new field so she taught geometry and astronomy to people from all over who came to Alexandria specifically to learn from her (Koch 95). Even when she was teaching, she continued learning and researching many different subjects. Hypatia mainly focused her studies on astronomy, astrology, and mathematics. She is most well known for her work on conic sections, which were first introduced by Apollonius (Adair). She developed the ideas of hyperbolas, parabolas, and ellipses while editing her text *On the Conics of Apollonius* (Adair). She was known for writing commentaries on books in which she gave explanations of difficult and dense topics that were easier to understand than the original books (Koch 95). Because of her work on several famous books and important topics, her work has endured through many centuries.

Hypatia lived in Egypt during the rise of Christianity, at a time when riots broke out often between the different religions (Adair). During this time, she became the recognized head of the Neoplatonist school of philosophy at Alexandria, a place where people questioned ideas and took nothing on blind faith, something that was frowned upon by the Christian church (Koch 96). In A.D. 412, Cyril, a man who opposed Neoplatonists, became the patriarch of Alexandria (Koch 97). He thought Hypatia would impede the rise of Christianity, so he spread rumors that if she were to be killed, it would make way for other religions to come together (Koch 97). This caused the spread of more rumors, some of which stated she was a witch and used black magic (Koch 97). In A.D. 415, Hypatia was attacked on her way home by a mob of people. She was stripped and killed with pieces of broken pottery, and then dragged through the streets. After her murder, several scholars fled Alexandria and the focus on education and learning began to decrease. As a result, mathematics was not formally studied in Alexandria for the next 1,000 years (Koch 97). Although Hypatia's life ended tragically, her important advancements in mathematics remained and she paved a tremendous path for women to follow.

Emmy Noether was born in 1882 in Erlangen, Germany. Noether was always interested in mathematics, but it wasn't until she finished her certification for teaching foreign languages that she decided to pursue mathematics as a career (Morrow 152). The conditions for women in mathematics were improving, so she decided to pursue what she truly enjoyed (Morrow 152). When she was 18, she started taking classes at the University of Erlangen. She was not technically allowed to enroll in classes, however, so she was simply given permission to audit the classes. After sitting in on classes for two years, she took the exam that would allow her to be a doctoral student in mathematics. She passed the test, and registered as a student at the University of Göttingen during the winter semester of 1903-1904 (Kimberling 10). After that semester, however, she went back to the University of Erlangen where she was finally allowed to register as a student (Kimberling 10). After studying at the university for three years, she was granted the second degree ever given to a woman in the field of mathematics (Taylor). Because she was a woman, the University of Erlangen would not hire her as a professor, so she began helping her father at the Mathematics Institute in Erlangen (Taylor). She began doing research there, and helped teach her father's classes when he was sick. Eventually she began to publish papers on her work. Soon after World War I ended, Noether was invited to the University of Göttingen to work on one of Einstein's theories with Felix Klein and David Hilbert (Taylor). Klein and Hilbert invited Noether because they felt that despite her gender, her expertise could help them with their progress. After a short amount of time, she was given a job as a lecturer at the University of Göttingen, although she still was not paid for her work (Taylor). Three years later, though, she began receiving a small salary (Taylor). Noether was known for a very fast-paced teaching style that was difficult to follow, forcing her students to create ideas of their own (Taylor). Because of this, many of her students became great mathematicians themselves (Taylor).

When the Nazis took control of Germany in 1933, Noether sought refuge in the United States, where Bryn Mawr College had offered her a teaching position (Taylor). Noether is most known for her work in abstract algebra, specifically rings, groups, and fields (Taylor). The structure known as Noetherian rings was named in her honor. Noether changed the way mathematicians look at the subject and she "cleared a path toward the discovery of new algebraic patterns that had previously been obscured" ("Profiles of Women"). She was extremely involved in the development of an axiomatic approach to mathematics (Henrion 68). Noether taught at Bryn Mawr College until her death in 1935. After her death, Albert Einstein wrote in a letter to the New York Times,

> In the judgment of the most competent living mathematicians, Fräulein Noether was the most significant creative mathematical genius thus far produced since the higher education of women began. In the realm of algebra in which the most gifted mathematicians have been busy for centuries, she discovered methods which have proved of enormous importance in the development of the present day younger generation of mathematics. (Osen 151)

Noether was a highly respected mathematician. There is a joke among mathematicians: "There have only been two female mathematicians. One was not a woman; the other was not a mathematician" (Henrion 68). Noether's colleagues did not see her as a typical woman, and she was often referred to as "Der Noether," which is a masculine title. Many believe that it was because of this that she was more accepted in her field. Noether will forever be recognized as an exceptional mathematician, author, and teacher.

Sofia Kovalevskaya (various spellings found in different sources) was born in 1850 in Moscow, Russia to a family of minor nobility. She is the woman referred to in the joke above as not being a mathematician. She was raised by a very strict governess, which resulted in her being very nervous and withdrawn for most of her life (Wilson). When she was very young, the walls of her room were covered in her father's old calculus notes, due to a lack of wallpaper (Wilson). Kovalevskaya studied these notes, as well as discussed abstract and mathematical concepts with her Uncle Peter. Kovalevskaya's father did not believe women should be highly educated, so when she showed skill in mathematics, he told her she was to stop her study of the subject (Beal 102). She continued to study mathematics, but hid it from her father and governess. At the age of fourteen, she taught herself trigonometry in order to understand a book that she was reading. The author of the book, also a neighbor to her family, was so impressed by Kovalevskaya's knowledge and skill that he convinced her father to let her study mathematics. After finishing secondary school, she wanted to continue her education. The nearest university that would accept women, however, was in Switzerland and unmarried women were not allowed to travel alone. So in September 1868, she married Vladimir Kovalevskaya. Two years later, Kovalevskaya began to study under Karl

Weierstrass at the University of Berlin (Wilson). She was not allowed to officially register at the university, but she studied under Weierstrass for four years. She is quoted saying, "These studies had the deepest possible influence on my entire career in mathematics. They determined finally and irrevocably the direction I was to follow in my later scientific work: all my work has been done precisely in the spirit of Weierstrass" (Wilson). In July 1874, Kovalevskaya received her doctoral degree from the University of Göttingen.

After having trouble finding work, Kovalevskaya returned to her family in Moscow. In 1878, she and Vladimir had a daughter, and while at home taking care of her, Kovalevskaya worked on developing her literary skills, writing fictional stories, theater reviews and scientific articles (Wilson). In 1880, Kovalevskaya was still struggling to find work in the mathematics field, so she moved back to Berlin, but without Vladimir. Shortly after arriving there, she heard that Vladimir had committed suicide after all of his business ventures had collapsed (Wilson). Kovalevskaya was devastated and threw herself into her work. She spent the next two years working on a research project in Berlin and Paris (Beal 105). In 1883, she was invited to lecture at the University of Stockholm by a former student of Weierstrass. After six months at the university, she was offered a five-year contract as a professor of mathematics (Beal 105). During this time her career began to flourish. She was appointed as an editor of the new journal *Acta Mathematica*, was made Chair of Mechanics, and gained tenure at the University of Stockholm (Beal 105). In 1888, she entered her paper, "On the Rotation of a Solid Body about a Fixed Point," in the Prix Bordin competition through the French Academy of science and won (Wilson). Her theory was so profound, and her paper so highly regarded that the prize money was increased from 3000 to 5000 francs (Beal 106). Around this time, she met another man, Maxim Kovalevsky. They were both extremely dedicated to their work, and neither wanted to give their work up for the other. In 1889 she was elected an associate of the Imperial Academy of Sciences, a huge honor since a woman had never before been elected (Beal 106). Shortly after her election, she returned to Stockholm, and although she frequently visited Maxim in France, she became very depressed, and eventually developed pneumonia. On February 10, 1891, Sofia Kovalevskaya died. Sofia Kovalevskaya fit the traditional views of a woman, and therefore struggled throughout her career to find acceptance in the field of mathematics (Henrion 69). However, she is recognized for publishing many groundbreaking theories as well as laying a foundation for future mathematicians to build upon.

Mary Ellen Rudin was born in Texas in 1924 to a middle-class family. Her father was a civil engineer and her mother was a high school English teacher (Carr). After graduating from high school, Rudin enrolled at the University of Texas, where she first became interested in mathematics. Before she came to the University of Texas, she knew very little about mathematics. When she came to the university, R.L. Moore took her under his wing, and he helped her build her independence in mathematics ("Mary Ellen Rudin" 291). R.L. Moore was known for encouraging his students to do original research. He inspired Rudin to pursue a career in mathematics. She wrote a thesis on a counter example of a well-known conjecture, using a technique now called "Building a Pixley-Roy Space" ("Mary Ellen Rudin" 290-1). She received her bachelor's degree in 1944, and her doctoral degree in 1949, both from the University of Texas (Carr). When asked in an interview in 1986 how she felt about her mathematical education, she replied,

> I really resented it, I admit. I felt cheated because, although I had a Ph.D., I had never really been to graduate school. I hadn't learned any of the things that people ordinarily learn when they go to graduate school. I didn't know any algebra, literally none. I didn't know any topology. I didn't know any analysis – I didn't even know what an analytic function was. I had my confidence built, and my confidence was plenty strong. ("Mary Ellen Rudin" 291)

She explained that this was because of the way R.L. Moore taught her. She was discouraged from reading any mathematical papers or works by other mathematicians, and she was simply taught to create her own ideas and theories. She only knew what Moore taught her, and never branched out from that ("Mary Ellen Rudin" 291). He helped her along the entire road to getting her bachelor's and doctoral degrees. After finishing her doctoral degree she taught at Duke University for four years. However, she never actually applied for this position, but rather Moore found the job for her and told her that was where she would be going ("Mary Ellen Rudin" 292). In her 1986 interview, Rudin admitted that she never applied for a job in her life ("Mary Ellen Rudin" 292).

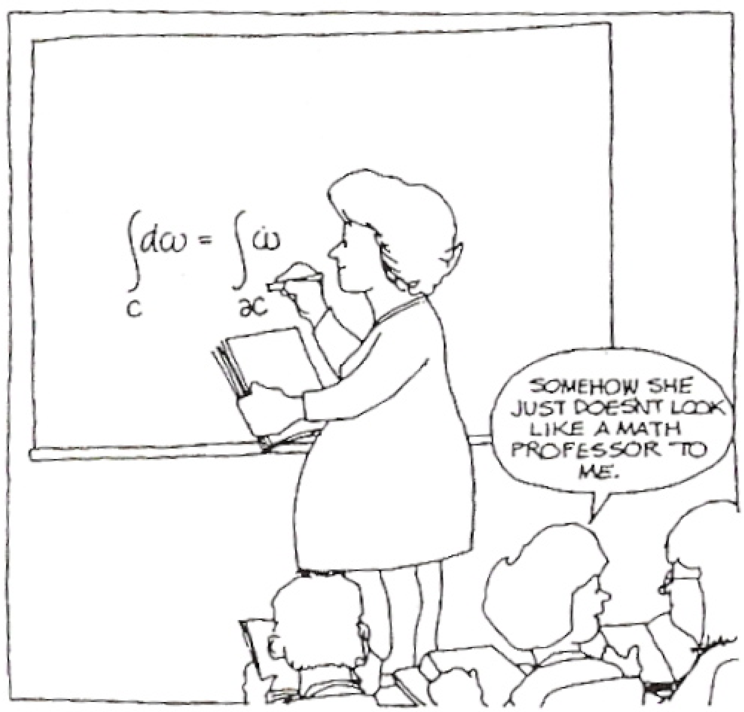
In 1953 Rudin married Walter Rudin, and they moved to New York, where she taught as a visiting professor at the University of Rochester for five years (Carr). They then moved to Wisconsin, where both she and her husband both accepted positions at the University of Wisconsin. In 1963, Rudin was the recipient of the Prize of Nieuw Archief voor Wiskunde from the Mathematical Society of the Netherlands (Carr). Rudin served as a lecturer at the University of Wisconsin until 1971 when the nepotism rules preventing spouses from working at the same university were eliminated and she was promoted to full professor (Meyer 197). In 1981, Rudin was the first to receive the Grace Chisholm Young professorship at the University of Wisconsin (Meyer 197).

Rudin continued conducting research throughout her time as a professor. Her work mainly focused on set-theoretic topology and she produced around seventy research papers on the construction of counter examples (Carr). Throughout her career, she has been involved in a number of different mathematical associations, including the Mathematical Association of America, the Association for Women in Mathematics, the Association for Symbolic Logic, and the American Mathematical Society (Carr). From 1980-1981, Rudin served as the Vice President of the American Mathematical Society (Carr). Among her busy life as a professor and scholar, Rudin and her husband had four children. Rudin made it a point to immerse herself fully into both of her passions: her family and mathematics. She never let her devotion to her career get in the way of caring for her family, and she did not let her family stop her from having a career. She found a way to balance the two, so that she could be exceptional at both. Mary Ellen Rudin is an exceptional woman. Not only was she a great mathematician and researcher, but she found time to have a family and was able to find a perfect balance of the two.

All of these women have made exceptional contributions to the mathematics field, but their experiences have not been without discrimination. Some specific hurdles that women have faced along with other variables that have been found to affect women's achievement in mathematics will be discussed in the next chapter.

The Effects of Gender on Mathematics Achievement

Although there have been many improvements for women in the mathematics field in recent years, which will be discussed later on, the road to where we are now has not been an easy one. For centuries, women in mathematics have had to endure many hardships and discrimination based on their gender. It was believed that being both a woman and a mathematician were incompatible (Henrion 67). Being a woman in mathematics was rough, as it was hard to be accepted as both a woman and a mathematician without facing criticism.



Traditionally, mathematics is identified with the realm of the mind, and women are associated with "bodies, children, hearth, and home" (Henrion 69). As represented in the cartoon above from Claudia Henrion's book *Women in Mathematics: The Addition of Difference*, it has been tough for women to be accepted in the mathematics field because they are expected to fit a certain stereotype. Not only is the professor in the cartoon a woman, she is also pregnant. The stereotypes of women in mathematics include being unattractive, unmarried, and a "schoolmarm". In her book, Claudia Henrion said that women in mathematics were sometimes thought of as women who never had the opportunity to marry or lead a conventional life, so therefore they turned to mathematics as a consolation prize (Henrion 67-8). She states that being a woman in mathematics was hard because it was a lose-lose situation. If women dedicated themselves too much to mathematics and their careers, they were judged harshly as a woman. But if they embraced the more stereotypical roles or responsibilities of a woman by getting married and having a family, they were not taken seriously as a mathematician (Henrion 69). Women were expected to be exceptional both at mathematics and in their womanhood, and failure to do so furthered the belief that women and mathematics were incompatible. When the director of the Courant Institute Cathleen Morawetz was interviewed about women and their ambition, her interviewer, who was a man, expressed that women's ambition represents "a threat to the men" (Henrion 71). Looking into it further, it is thought by some that when women are ambitious, not only are they invading the "men's sphere," otherwise known as the work force, but they tend to abandon their traditional roles of being a wife and mother.

Far fewer women chose to study mathematics beyond high school, and this is the problem. Why is this the case? Some factors that seem to contribute to this are females' lesser confidence in learning mathematics, a belief that mathematics is not useful, and males' belief that mathematics is a male domain (Fennema 218). But where does this all begin? Does it start early on in the education track, or does it not set in until later?

Reviews published before 1974 all agreed that sex-related differences in mathematics achievement showed up by late elementary school (Fennema 209). Male superiority was always found to be evident by the time students reached late elementary school or junior high. “The evidence would suggest to the teacher that boys will achieve higher than girls on tests dealing with mathematical reasoning” (Fennema 209). However, reviews published since 1974 have not all agreed with these findings. Some reviews found little to no sex-related differences in mathematics achievement in elementary school, junior high, and high school. They did find that there were certain cognitive tasks that men were better at than women, but they also found other tasks that women were better at than men (Fennema 210). However, Maccoby and Jacklin disagreed with these findings in their 1974 review, stating, “sex difference that [is] fairly well established…is that boys excel in mathematical ability” (Fennema 210). There are mixed reviews, which show that there is not actually a solid consensus on whether sex-related differences in mathematics achievement exist.

In her article examining sex-related differences in mathematics achievement, Elizabeth Fennema makes references to four major studies of this topic: Project Talent, the National Longitudinal Study of Mathematical Abilities (NLSMA), the First National Assessment of Educational Progress (NAEP-I), and the Fennema-Sherman studies.

Data for Project Talent were collected around 1960 and assessed the mathematics achievement of high school students in the United States. The data indicated that sex-related differences in achievement did not show up until about twelfth grade when it was found that boys tended to do better than girls in mathematics (Fennema 210). The problem with this study was that there was no control over how many mathematics courses the students had previously taken. The boys in the study had taken more courses than the girls, a likely contributor to their higher achievement (Fennema 210). In 1975, a follow-up to this study was conducted that found that the differences between males and females had been reduced between 1960 and 1975 (Fennema 210).

Data for the NLSMA were gathered from 1962 through 1967. In these studies, whenever significant connections between sex and any other variable were found, analyses were done independently by sex. These results, however, have been inadequately reported and interpreted, so they do not contribute much to the study of sex-related differences (Fennema 211). These studies did find, though, that girls excelled more at the comprehension level, whereas boys excelled more at the application and analysis level (Fennema 211). The size and the significance of the differences between the male performances and the female performances from this study are unknown.

The NAEP-I study was conducted between 1972 and 1973. In a widely publicized quote from this study, it was said, "In the mathematics assessment, the advantage displayed by males, particularly at older ages can only be described as overwhelming" (Fennema 211). The data showed that males outperformed females at age seventeen and between the ages of twenty-six and thirty-five (Fennema 211). However, at ages nine and thirteen differences were minimal and sometimes in favor of females (Fennema 211). Similar to the Project Talent data, though, are the problems with this study. There was no control over educational or mathematical background, so the differences in achievement at the ages they found could be attributed to the differences in mathematical coursework (Fennema 211). Notice that at ages nine and thirteen the mathematical achievement was very similar between the sexes, and this is when the mathematical background would be the most similar.

Data for the Fennema-Sherman study were collected between 1975 and 1976 and looked at mathematics achievement in sixth through twelfth graders at four different schools. The study examined different levels of mathematical learning along with variables believed to be linked to sex-related differences in mathematics achievement. The sample was carefully selected, with close attention paid to the subjects' mathematical backgrounds. In sixth through eighth grades it was found in one of the four schools that females excelled over males in a low-cognitive-level mathematical task, and in another school males excelled over females in a high-cognitive-level mathematical task (Fennema 211). No other significant data from this study were reported.

There is not much that can be concluded from these studies, or any other studies that have been done on sex-related differences in mathematics achievement. Either there were no significant differences that could be detected, or the differences could have been attributed to other factors. For these reasons, there is not much resolve in this matter. It has been found, however, that there are significant sex-related differences when it comes to the studying of mathematics. Data collected during the 1975-76 academic school year at the University of Wisconsin indicate that the number of male and female students enrolled in mathematics classes is about the same in algebra and geometry, but there is a significant drop in the number of women enrolled in higher level mathematics courses (Fennema 213). This is represented in the table below from Fennema's book *Sex-Related Differences in Mathematics Achievement: Where and Why*.

Table 2 Males and Females Enrolled in Mathematics Courses in Wisconsin

Course	*Males*	*Females*
Algebra*	41,404	41,579
Geometry	20,937	20,280
Algebra II	11,581	9,947
Pre-calculus	3,234	1,917
Trigonometry	4,004	2,737
Analytic geometry	1,752	970
Probability/statistics	1,113	581
Computer mathematics	3,396	1,481
Calculus	611	262

Source: Konsin, 1977.
Note: Data obtained from Wisconsin Department of Public Information Enrollment Statistics, 1975–76.
*Students enrolled in one-year and two-year courses.

Fennema discusses several different contributing factors as to why women leave college knowing significantly less mathematics than men. These factors fall into three broad categories: cognitive, affective, and educational variables. Cognitive variables include the amount of time spent studying mathematics and spatial visualization, or the ability to visualize objects and manipulate them in one's mind (Fennema 213-5). However, there is not sufficient evidence to prove that spatial visualization can account for significant differences in mathematics achievement of males and females (Fennema 213-5). Affective variables include confidence and anxiety of the person, the stereotype of mathematics as a male domain, the belief in the personal usefulness of mathematics, and intrinsic motivation (Fennema 215-7). However, there is little evidence to show that intrinsic motivation in females is less than that of males (Fennema 215-7). Educational variables include teachers and school organization (Fennema 217). All of these variables can have an effect on sex-related differences both in mathematics achievement and the studying of mathematics.

In a study published in 1999, Steven Spencer, Claude Steele, and Diane Quinn analyzed the affect of stereotype threat on the performance of women in mathematics. Spencer, Steele and Quinn acknowledge that there is a negative stereotype that women have weaker mathematical abilities (Spencer, Steele and Quinn 1). They defined stereotype threat to be the risk women face of being judged by this negative stereotype when they perform mathematical tasks (Spencer, Steele and Quinn 1). They picked groups of highly qualified individuals with strong backgrounds in mathematics and did two studies. The purpose of the first study was to demonstrate the differences in mathematical achievement between men and women when stereotype threat was high, and the purpose of the second study was to show that when stereotype threat is lowered, women perform better (Spencer, Steele and Quinn 1, 8). The researchers mentioned a study in which seventh and eighth grade students, all with the same amount of prior mathematics coursework, were given the mathematics section of the Scholastic Aptitude Test (SAT) (Spencer, Steele and Quinn 24). The students who scored above a 700 were overwhelmingly males, outnumbering the females by a factor of 10 to 1 (Spencer, Steel, and Quinn 24). The conductors of this study however did not acknowledge that just because students are in the same class does not mean that they have the same experiences. That is what Spencer, Steele and Quinn tried to achieve in their study by eliminating any pressure that students may feel when taking tests: a level playing field. They found that when the stereotype threat was eliminated, women performed better than when they felt external pressure (Spencer, Steele and Quinn 25-6). The results of this study clearly showed that the tendency of women to perform lower than men in mathematics isn't due to lack of ability or knowledge, but rather the societal stereotypes and pressures that they feel when taking tests (Spencer, Steele and Quinn 25-6).

In a book dedicated to their daughters, Stephen Ceci and Wendy Williams explain why they believe women do not pursue careers in mathematics. They believe that women simply have higher preferences for careers in fields not relating to mathematics, and the choices in career often have to do with fertility and its consequences for work (Ceci and Williams 180). They explain that women choose to start families at times that jeopardize career progress, and would have even greater effects in a mathematics-related career (Ceci and Williams 180). They acknowledge that smaller effects such as spatial and mathematical ability, hormones, stereotype threat, and biases are not trivial, but yet they have smaller effects on the pursuit of careers in mathematics than the preference/choice factor (Ceci and Williams 180). They describe how various factors contribute to the underrepresentation of women in the mathematics field:

> …(1) fewer women scoring at the right tail in math, which reduces their chances of acceptance into math-intensive graduate fields for which the GRE-Q scores are an important consideration for admission; (2) fewer women who do score at the right tail in math preferring to enter mathematical fields even though they have the mathematical aptitude to be successful, preferring instead more organic, people-oriented fields; (3) fewer women opting to compete for tenure-track posts upon receipt of their doctorates; (4) more women leaving the field for family reasons; and (5) more women leaving the field as they advance, for career changes.

> Note that none of these factors entails overt discrimination against women. (Ceci and Williams 188-189)

A recent analysis of 100 studies found that gender-related differences have declined in recent years (Leder 13). However, differing variables in the different studies make cross-study comparisons difficult. Leder lists a large number of variables that are studied in relation to gender differences in mathematics, and a majority of the variables have to do with one's beliefs. They list variables such as confidence, perceived usefulness of mathematics, sex-role congruency, motivation, fear of success, attributional style, learned helplessness, mastery orientation, and performance following failure (Leder 15). It is important to acknowledge that a majority of the variables that potentially affect how women perform in mathematics are not even related to actual ability or knowledge, but rather how women perceive themselves and their ability.

In a book on how to help children learn to love math, Jo Boaler talks about her experiences working in a high school classroom and observing differences between boys and girls. She noticed that girls were more interested in why certain methods worked, where they came from and how they fit in with other methods they had learned, while boys were more concerned with simply getting the correct answers (Boaler 124-6). The boys were more worried about racing through the book and finishing before everyone else, but the girls were concerned with understanding the concepts involved in answering the questions. Boaler observed that the teacher of the class would not answer the questions the girls had, so they did not completely understand the concepts and how to apply them. In a survey given to the students, ninety-one percent of the girls chose understanding as the most important aspect of learning mathematics, whereas only sixtyfive percent of boys thought it was the most important and the rest of the boys said that memorization of rules was the most important aspect (Boaler 126). At the end of three years, the students took a national exam and the girls performed considerably lower than the boys (Boaler 126). When the girls did not get the depth of understanding that they wanted, they tended to run away from the subject, which led to lower achievement scores on tests (Boaler 126). Boaler acknowledged that while one cannot assume that none of the boys wanted a deeper understanding of the subject and methods, there was a higher percentage of girls who sought this deeper comprehension (Boaler 131).

Throughout all this research, people were attempting to figure out how sex relates to mathematics achievement. It has become evident that there is no one right answer to the question of what the extent of these differences is and why they exist. The data has been all over the board: some experiments found differences in favor of women, some in favor of men, and some found that there were no differences between male and female mathematics achievement. The difficulty with these experiments comes when you try to compare data from unequal samples. There are many factors that vary throughout the different experiments, which make it difficult to compare the data. The overwhelming consensus from the projects, however, is that women and men both have equal potential to be great in mathematics; they just need the right atmosphere and attitude.

Personal Experiences of Female Mathematicians in the Claremont Colleges

There are many women in the Claremont Colleges who have made significant impacts within the field of mathematics. However, despite their contributions, every single one of them has experienced some kind of discrimination based on their gender at one time or another. I sat down with a few of them and asked them the following questions: What has your overall experience in the mathematics field been like? What made you choose to go into the mathematics field? What would you consider to be your greatest accomplishment or addition to the mathematics field? Have you experienced any prejudice because you are a woman, either in school or in your job? If so, how did you deal with that prejudice? And finally, how do you think we can change the way women in the mathematics field are looked upon?

Judith Grabiner is a professor of the history of mathematics at Pitzer College. When she was in high school, mathematics was the best-taught subject at her school, and she was good at it. She continued to take mathematics throughout college, and had great mathematicians as professors, which encouraged her to pursue mathematics as a career. When she began her undergraduate studies at the University of Chicago, female mathematics majors were very rare, and some universities did not even admit women as graduate students. In her last year of college, she decided that she was going to Harvard University for graduate school. The three best programs were Harvard, Princeton, and Chicago. She had already been to Chicago, and Princeton did not admit women, so Harvard was the best choice for her. During her first year of graduate school, she took an Abstract Algebra class, and was one of two women in a class of about one hundred. When a fellow male student at her college asked her what she was majoring in, he was floored when she said mathematics, but then quickly responded with “Oh, are you going to teach?” This may not appear to be direct discrimination, however the implication is that women who major in mathematics will simply become teachers, and not go on to become high-level researchers.

When looking for jobs after her postdoctoral studies, she and her husband found that there were anti-nepotism laws that kept colleges from hiring two people from the same family. This made it much harder for women to get good jobs, especially Grabiner because her husband is also a mathematician. After being hired for her first job at the University of California at Santa Barbara, a colleague told her that while she was being considered, an older man made a comment that a woman had never been in the department. Grabiner dealt with discrimination by being the best she could possibly be (Grabiner). She said she is very thankful that her mentor and her thesis advisor were both strong feminists and promoted the academic success of their female students (Grabiner).

Professor Grabiner believes that the most important thing we can do for women in mathematics is to educate students about the contribution of women to the mathematics field (Grabiner). She teaches a course titled “History of Math,” and in the beginning of this class her students are rarely able to name a woman mathematician outside of Claremont. After the course however, this once daunting task becomes easy for her students. She also believes that there needs to be not just one or two but a critical mass of women mathematics professors in every university and college mathematics department (Grabiner).

Professor Grabiner has received positive feedback from the mathematics community, especially for her written work. She has won seven “best article” prizes from the Mathematical Association of America (MAA), and has a new book titled *A Historian Looks Back*, just published last year by the MAA. Grabiner has done work on Cauchy, including writing a book titled *The Origins of Cauchy's Rigorous Calculus* published in 1981. She also did a course for The Teaching Company on DVD, based on a liberal arts course she teaches here in Claremont titled "Mathematics, Philosophy, and the 'Real World.'" Professor Grabiner has made many important contributions to the mathematics field, and more specifically to documenting and teaching the history of mathematics.

Erica Flapan is a mathematics professor at Pomona College. When she was young, mathematics was her favorite subject; she enjoyed it and was very good at it. She began tutoring other students when she was just twelve years old, and she was very good at explaining, so she continued tutoring throughout high school and college. By the time she reached Hamilton College, she knew she wanted to teach mathematics. As an undergraduate student, she was the only female mathematics major, and there were no other women in any of her mathematics classes. When she entered graduate school at the University of Wisconsin, Madison, there were forty students in her incoming class, only three of which were women, including her. Her first semester, Flapan actually took a topology class with Mary Ellen Rudin, who was one of only three women out of a faculty of one hundred. After the first semester, the other two women in her class dropped out, and she became the only woman in her class. Her first experience with discrimination based on her gender was while she was in graduate school. She won an award from her department for being the best teaching assistant, and shortly thereafter the chair of the undergraduate mathematics department called her into his office. She assumed that he was simply going to congratulate her, but instead he told her that she should drop out of the program (Flapan). He told her that if she went on to get her doctoral degree no man would want to marry her, and furthermore she would never be able to get a job anyway (Flapan). He said that if she got married and had children, any department would know she was not going to put much effort into her job because it was thought that women dedicated a third of their time to their husband, a third of their time to their children, and a third of their time to their job (Flapan). However, if she did not get married, schools would think she was neurotic and not want to hire her (Flapan). She complained to the chair of the graduate mathematics department, but he told her that the man was not dangerous because anyone he would try to persuade to leave would see he was crazy and not let him affect their education. Nothing was ever done to this professor. Flapan recalls that when she tried to work with other students in graduate school they would try to make passes at her, so it became awkward (Flapan). Flapan went on to earn her master's degree in 1979 and her doctoral degree in 1983, both from the University of Wisconsin, Madison. According to Flapan, the conditions for women in the mathematics field have changed over the years, but now when she goes to conferences, almost all of the other women are young, and there are very few women her age. Very few women her age chose to continue research after their education, most likely because of the availability of as well as the conditions for women in higher-level positions.

When Flapan was offered a position at Pomona College, the dean that hired her told her that salaries were non-negotiable. She wanted to stay in the area to be close to her husband, so she took the offer. Several years later, a man was hired and Flapan learned that his salary was higher than hers, despite the fact that she was more advanced, had been at Pomona longer, and had earned her doctoral degree earlier. Flapan went to the dean to question this, and he did raise her salary so that it was equal to the man's salary, but he did not raise it any higher than the salary of the new professor (Flapan). After being at Pomona for several years, Flapan was put up for tenure, and around the same time, she found out she was pregnant. She was the first woman to be tenured, and the chair of the department had made a comment about women not devoting themselves completely to their jobs, so she hid her pregnancy from the department. After she was tenured, the secretary of the department asked her if she was pregnant, and she did not feel the need to hide it anymore so she began to tell her colleagues.

When asked how we can change how women are looked upon in the mathematics field, Professor Flapan said that two of the major issues facing women today are the two-bodied problem (the difficulty of finding two mathematics jobs in the same geographic location) and not enough women at a higher research level in mathematics (Flapan). Flapan believes that we need to mentor and inspire more women to pursue mathematics beyond their undergraduate degree. She believes there needs to be a summer mathematics program for first and second year college females from Ivy league schools who are interested in mathematics; a summer program that excites them about careers in mathematics and provides them with mentors (Flapan). A program like this would encourage bright, young, talented women to pursue careers in mathematics and help get women into higher leadership positions in the field of mathematics.

Professor Flapan has mentored a tremendous number of students, particularly women, both through teaching at Pomona and at a summer school program for young women. She has had an impact on a great number of rising mathematicians. In regards to research, she has studied knot theory, more specifically symmetries of knots, as well as symmetries in graphs embedded in space. She has been a pioneer in that area and applications of that to study molecular symmetry. She has written many papers and also wrote a book related to this subject titled *When Topology Meets Chemistry*. Professor Flapan has made many additions to the mathematics field, both through her mentoring and through her research.

My next interview was with Professor Smith[*]. Professor Smith always liked mathematics, but never really thought it was something she would do for a living. She wanted to be a concert pianist when she was ten, and then she wanted to be a cellist. She actually dropped out of college to be a musician, and was a professional cellist for 10 years. When she had a baby, she realized that the life of a musician was not compatible with having a child, so she decided to go back to school (Smith). She started off at the University of California, Berkley majoring in chemistry, but she wasn't patient enough for all the experiments. She switched to computer science since she had been doing a lot with computers through music composition. She did not like the social aspects of the major, however, and the department was not very friendly (Smith). The part of computer science that she enjoyed was the theoretical part so she switched her major to mathematics. Even after graduating, she still did not know what she was going to do. At the encouragement of her female advisor, she applied to graduate schools and was accepted to a mathematics graduate program. She so thoroughly enjoyed it that she decided to become a professor.

[*] Professor requested to remain anonymous because of some of her experiences

Professor Smith's experience in the mathematics field has been challenging, but rewarding (Smith). It took awhile for her to become comfortable and feel like she belonged in the mathematics community (Smith). She explained that it is rare that you forget you are a woman in a male dominated field (Smith). When she was an undergraduate student at the University of California at Berkley, there were very few women, both students and professors. There was also a male professor on the faculty that was notorious for saying that women could not do mathematics. One semester, she had a professor that called her at home while he was grading her class' finals to tell her that she had not done very well on the test. He told her that he would give her a better grade if she agreed to go out with him. She turned him down and said she would take whatever grade she had earned, and it turned out the professor was bluffing (Smith)! She had actually done well on the test and he just wanted to see if she would go out with him. That situation was a little extreme, but little things like that happened all the time so she did not ever say anything about it. After she was hired at her current job, a faculty member made a comment to her that she was only hired because she was a woman. She said that she is constantly reminded of her gender, because mathematics is such a male dominated field (Smith). She was recently on a panel for the National Science Foundation and she was one of only two women on the panel of twelve. Whenever she spoke up, she felt like people thought she was representing the view of all womanhood (Smith).

When asked how we can change the way women are looked upon in the mathematics field, Professor Smith said it is important to continue presenting to the world women who are smart and womanly, to show that you do not have to look or act like a man to be successful; we need to continue to show women who are doing things in mathematics but have a feminine identity (Smith). She also believes that it is important to acknowledge that there are unsaid and sometimes invisible messages given to women discouraging them from pursuing mathematics, and counteract these messages by encouraging women that mathematics is something that they can do (Smith)! This idea needs to be emphasized early on in the education track so that children, especially girls, recognize from an early age that they can do whatever they want.

Professor Smith has been a big part of modeling cancer growth using mathematics. She was part of the early foundational work before the field expanded. She has also been very involved with programs that will increase diversity within the mathematics field including women along with other underrepresented groups. She has been involved with The EDGE Program, a program that has been going on for about thirteen years and focuses on enhancing diversity in graduate education, or more specifically encouraging women to attend graduate school. Professor Smith has been very instrumental in encouraging women to strive for a higher education and make their presence known in the mathematics field.

Talithia Williams is a mathematics professor at Harvey Mudd College. Professor Williams applied to college as an undecided major. When she applied, the National Aeronautics and Space Administration (NASA) was awarding scholarships to women majoring in math, science, and engineering. Since she needed money to go to college and had taken AP Calculus and AP Physics and done well, she decided to choose those two subjects as her majors (Williams). She went to Spelman College, which is a reputably famous college for black women, and it was a very supporting, nurturing and encouraging environment. Williams said that it was easy for her to be a mathematics major there. After finishing her undergraduate degree at Spelman and her master's degree at Howard University, she applied to two different graduate departments at Rice University for her doctoral degree. She was a very strong student and had proven herself capable, and yet she did not get into one of the departments. When talking with a professor in that department, he said they had previously had a student from Spelman College and she left after finishing her master's degree. They felt that Williams might do the same so they did not admit her to their program (Williams). Williams decided it best not to pursue the matter any further so she let it go and went to the other program.

Recently, she attended a conference in Chicago for statistics. When she got there, people were surprised to see her there and the woman at the check-in table asked her if she was in the right place. This happened on both the first and second days of the conference. At the end of the second day, Williams had a conversation with the woman at the check-in table about places to go and places to see in Chicago, simply to try to spark a conversation so she did not leave the conference feeling bitter. The next day, the woman gave her a very kind, warm welcome along with information pamphlets of must see things in Chicago. Once she had formed a connection with the woman, she was seen as belonging to the group. Professor Williams acknowledges that in the woman's defense all the other people at the conference were older white males, so it was not completely wrong to question her place there (Williams).

When asked how we can change the way women in mathematics are viewed, Williams said that women need to see themselves reflected in the discipline (Williams). Mathematics is seen very much as a male discipline, and women tend to not go into it because of this belief. There are very few women in leadership positions, and few women get recognized for their achievements. It is difficult for women to break into the higher realm where they would have the opportunity to take a leadership position or be given an award for research. Williams believes that the mathematics field needs to be more intentional on recognizing the achievements of women (Williams).

Professor Williams is most proud of finishing her doctoral studies. When she was an undergraduate student, she was shocked to find out that fewer than one hundred women had their doctoral degree in mathematics, so her goal in going to graduate school was to increase that number by one (Williams). It is hard for minorities and women at schools that are not intentional in their support of degree completion, so it was a huge accomplishment for her to finish. Professor Williams took it upon herself to redefine what it means to be a woman in mathematics. She painted her office red, displayed her faith on the wall, and she gets dressed up for work every day. She did not try to fit into the mold of what had been established for women mathematicians, but rather redefined it by being herself (Williams).

Rena Levitt is a visiting mathematics professor at Claremont McKenna College. Professor Levitt had always been drawn to mathematics her entire life. As a young child she went to a Montessori school, and she was always good at mathematics and very interested in the subject, so the school helped her flourish in that area. She did mathematics almost the entire day, playing games with numbers and shapes, and various other activities. She was doing high school mathematics before she reached the sixth grade! When she left the Montessori school, she received negative social reaction, and her middle school did not want to send her to the high school to take mathematics classes at her skill level, so her mathematics education was held back. She was not very popular because she was so smart, and the boys did not like that she was so smart, so she started to pull back and got more involved and interested in other subjects, like drama and English (Levitt). She knew in high school that she wanted to be a professor; she just wasn't sure which subject she wanted to teach (Levitt). When she first enrolled in the University of Wisconsin, Milwaukee, she planned to be an English major, but she kept taking mathematics classes as well because she enjoyed them. Levitt came back to mathematics in a roundabout way. She changed her major from English to philosophy, but decided the only thing she really liked about philosophy was the logical side, so she finally changed her major to mathematics.

It did not occur to Professor Levitt that she was different from most of the other people in her major until the end of her undergraduate career. She then started to notice differences more and more in graduate school and afterwards in jobs as well. Looking back on her experiences, she realizes that the numbers were dropping off. Towards the end of most of her classes, there would only be two or three women in each class. While in graduate school at the University of California, Santa Barbara, she had a professor send her an email saying she needed to attend a certain seminar because there were no other women attending, even though the seminar did not pertain to her research. During her fifth year in graduate school, she had a daughter, and although she was supposed to graduate that year, she stayed for another year. She received a dissertation fellowship that granted a quarter off to students, and was meant to help people who were doing a significant amount of research. It was an honor to receive the fellowship, and she was extremely thrilled and proud to be given that opportunity. The celebration was cut short, however, when one of the men on the board told her they gave her the fellowship because they thought she could use the time off since she had a daughter (Levitt).

When asked about the problems facing women in mathematics and how we can help change how women in the field are looked upon, Levitt recognized that the hardest things for women to deal with are the two-bodied problem and children (Levitt). People make harsh judgments on women based on their marital status and their family situation. Levitt wants to have another child, but she says it is very hard to figure out how to fit it in, especially with the pressure from both the outside and that which she puts on herself (Levitt). However, despite these issues, Levitt believes that a lot of the stereotypes are erased, and women are viewed in a more positive way. She recalls her experiences being very positive for the most part and does not remember anyone telling her that she could not be a mathematician (Levitt).

Although Professor Levitt is a younger, newer professor, she has made some great contributions to the mathematics field. As a graduate student at the University of California at Santa Barbara (UCSB), she organized a seminar for women in mathematics at her school. She and her two friends noticed the trend of women dropping out, so they started a seminar to help women figure out what was happening and how to change it, as well as discover the past and learn from it. The seminar was titled the Hypatian Seminar, and they brought in female speakers to give talks about important issues. The seminar also served as a mentoring program, bringing in graduate students to network with and talk about the job market, qualifying exams and other topics. The Hypatian Seminar still continues today at UCSB. Levitt is a great mentor to the students around her, both through programs built to bring up underrepresented students, and mentoring students in her classes.

My final interview was with Professor Johanna Hardin, a mathematics professor at Pomona College. Professor Hardin grew up in a house that emphasized mathematics and the sciences. She always did really well in mathematics; it came easily to her and she enjoyed her mathematics classes more than her other classes. She thought she was going to be an actuary like her father, but after attending Pomona College as an undergraduate, she fell in love with the school and decided she wanted to become a professor (Hardin).

Despite being in the minority as a woman in most of her mathematics classes, Hardin says she has had a very positive experience in the field (Hardin). During Hardin's first three years as an undergraduate student at Pomona College, Professor Flapan was the only female professor in the mathematics department. It wasn't until Hardin's senior year that another woman was hired. However, she always felt very supported by the department in spite of the lack of female faculty (Hardin). She attended the University of California, Davis for graduate school where she received her master's and doctoral degrees. Her classes were made up mostly of men, and women tended to drop out more than men, but she never felt like she didn't belong. When she graduated with her doctoral degree, about three or four of the faculty were women, and one of them was involved in a lot of administration and took on higher roles. While the majority of the faculty was men, women were still represented in the department, and provided support for Hardin. Hardin did her postdoctoral work at the Fred Hutchinson Cancer Research Center in Seattle, where a lot of the faculty was made up of women with their doctoral degrees. Looking back, she does not feel like she faced much discrimination, but has more recently seen the role of gender as a faculty member at Pomona (Hardin). In her classes, she has noticed that men feel more confident in their abilities, so they tend to answer more questions than women, and women tend to discredit their abilities more often (Hardin).

Professor Hardin believes that the conversation about women entering higher education institutions and seeking higher-level jobs has played a major role in the increased status of women in the mathematics field (Hardin). She believes that women need to recognize their differences in teaching styles and mannerisms and use them to their advantage (Hardin). Women also need to stop discrediting their skills and their knowledge, and learn to own their intelligence. Another issue that women face is the issue of raising a family. Often women start thinking about having families and stop being engaged, stop looking for promotions, stop starting interesting projects, and stop progressing in their careers. They think about leaving their jobs way before they actually leave, so they have left mentally. Women need to be in the work force, and make their presence known.

Professor Hardin has had a great impact on her students. Her classes have big enrollments, and she has many students wanting to work with her. She has also done research and written papers on analyzing clustering, correlation, and outlier detection.

The interviews in this paper have been organized by the amount of discrimination that the professors faced. It is interesting to note that with the exception of one professor, the order of the interviews in this paper coincides with the year these professors graduated; the earlier the professors graduated from school, the more discrimination they faced. However, although all of the professors I interviewed came from different backgrounds and areas of study, they all faced some degree of discrimination at some point in their education or career. Despite this, they have all flourished and made significant contributions to the field of mathematics, and especially to the Claremont Colleges.

Changing Trends for Women in the Mathematics Field

Over the years, there have been many improvements for women in the mathematics field. There is still some discrimination, and men still outnumber women in the field, but that is beginning to change. The discussions that are now occurring related to this topic have been a huge contribution to the start of these changes. People now talk about the way things are for women in this field, why they are this way, and how we can strive to improve them.

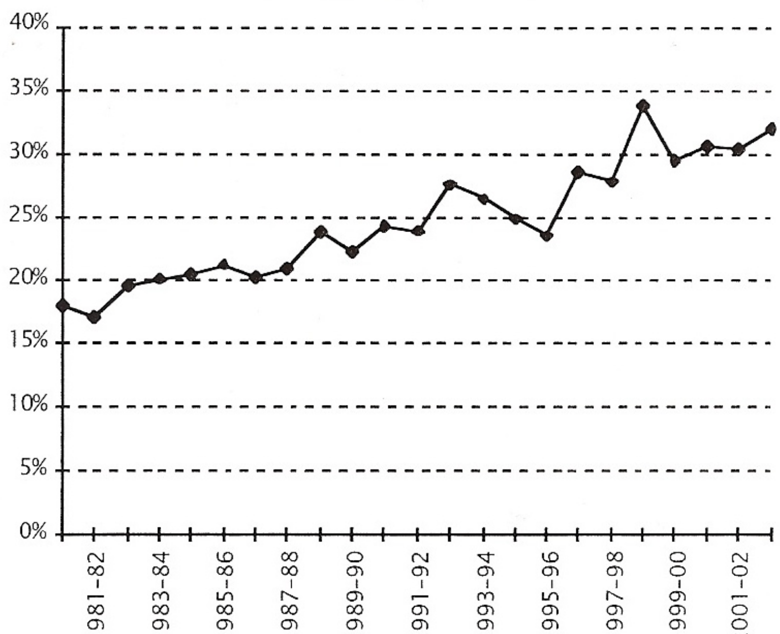
Every year, annual survey data in the mathematical sciences field are collected concerning faculty salaries, employment experiences of new doctoral recipients, hiring statistics, and doctorates granted with relation to sex, race/ethnicity and citizenship, among other things ("Annual Survey"). Data are published four times a year in the *Notices of the American Mathematical Society* (AMS), a mathematical journal "aimed at professional mathematicians" ("Notices"). In the first report in 2003, data were collected from two questionnaires sent out to departments in May, and a follow-up questionnaire sent out in October (Kirkman 218). In this report, the preliminary count for new doctoral recipients in 2002-03 was 1,017 (Kirkman 220). Of those 1,017 doctoral recipients, 304 were women, making up 30% of the total mathematics doctoral recipients (Kirkman 219). This number was up by 14 from the previous year (Kirkman 219). Of the 1,017 doctoral recipients, 489 were United States citizens, and 157, or 32% of those were females, a number that was 30 less the previous year (Kirkman 219). The all-time high for United States citizen, female doctoral recipients was 187 in the fall of 1998 (Kirkman 219). The following chart and graph from the 2003 Annual Survey of the Mathematical Sciences represent the number and percentage of United States citizen doctoral recipients by sex.

Table 8: U.S. Citizen Doctoral Recipients by Sex

Year	Total U.S. Citizen Doctoral Recipients	Male	Female	% Female
1980-81	567	465	102	18
1985-86	386	304	82	21
1990-91	461	349	112	24
1995-96	493	377	116	24
1996-97	516	368	148	29
1997-98	586	423	163	28
1998-99*	554	367	187	34
1999-00	537	379	158	29
2000-01	494	343	151	31
2001-02	418	291	127	30
2002-03	489	332	157	32

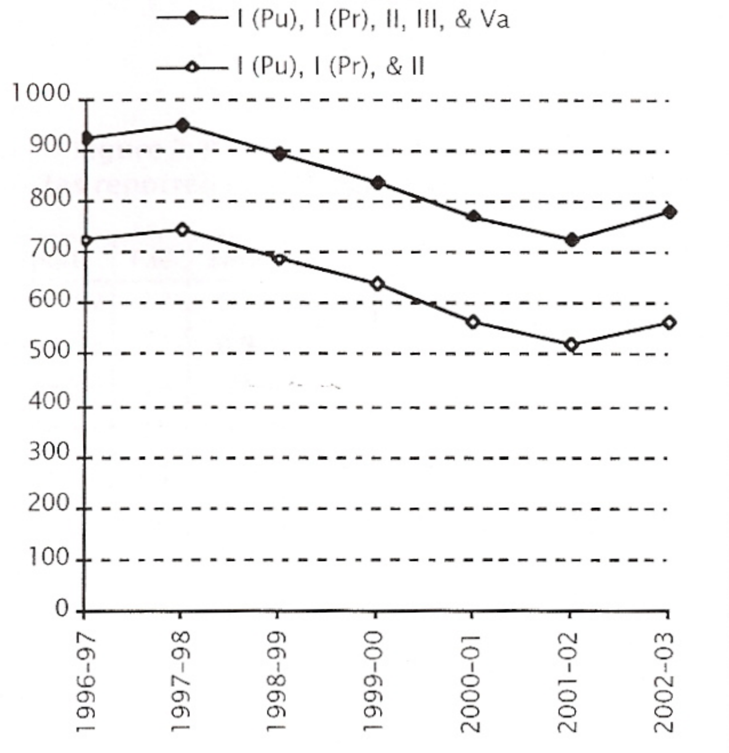
*Prior to 1998-99, the counts include new doctoral recipients from Group Vb. In addition, prior to 1982-83, the counts include recipients from computer science departments.

Figure 4: Females as a Percentage of U.S. Citizen New Doctoral Recipients



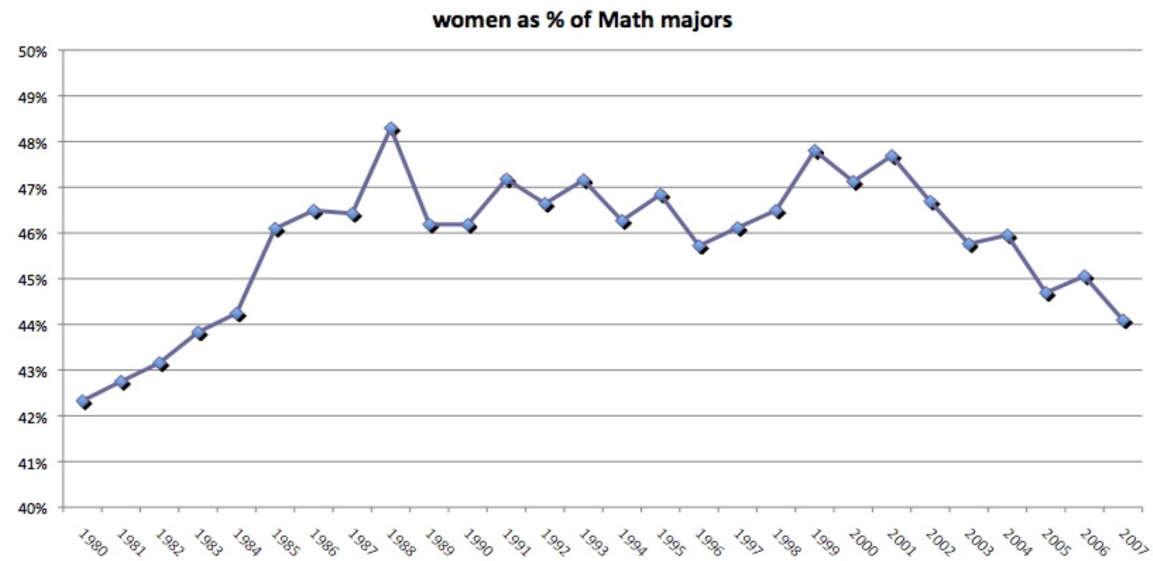
As shown in these graphs, the percentage of United States female doctoral recipients has been increasing over the years. It has dipped a few times, but for the most part it has been slowly rising. For various reasons, more and more women are choosing to pursue a higher education in mathematics. It is interesting to note, however, that the number of total new doctoral degrees awarded was steadily declining from 1997 until 2002. The following graph from the 2003 Annual Survey of the Mathematical Sciences shows this trend. In this graph, the two lines represent the combinations of different groups the study examined. The graph represents the new doctoral recipients from the following groups: I (Private), I (Public), II, III, and Va. Departments are split up into groups based on several different characteristics, and subdivided "according to their ranking of 'scholarly quality of program faculty' as reported in the 1995 publication *Research-Doctorate Programs in the United States: Continuity and Change*" (Kirkman 233). Group I is made up of forty-eight departments with scores between 3.00 and 5.00, and is further split up by private institutions and public institutions (Kirkman 233). Group II is made up of fifty-six departments with scores between 2.00 and 2.99 (Kirkman 233). Group III is made up of the remaining United States departments with a doctoral program, including departments that were not included in the 1995 ranking of program faculty (Kirkman 233). Group Va is made up of United States departments in applied mathematics/applied science (Kirkmann 233).

Figure 1: New Doctoral Degrees Awarded by Combined Groups, Fall Count

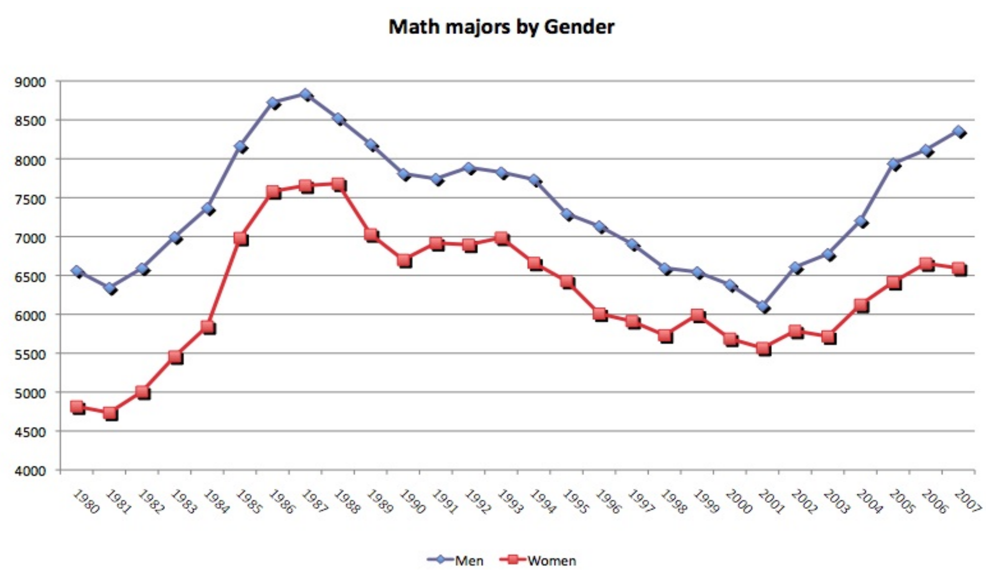


It is extremely interesting to see this decline in total doctoral recipients, when the percentage of female doctoral recipients was increasing during these years. Perhaps the number of male doctoral recipients dropped, but the number of women stayed about the same or increased. It would be interesting to see further data related to this.

In an online journal published by the Mathematical Association of America, David Bressoud wrote an article in September 2009 titled “We Are Losing Women from Mathematics.” In it, he discusses the decline of undergraduate female mathematics majors. He puts forth a graph showing the decline, as well as a graph showing mathematics majors by gender.



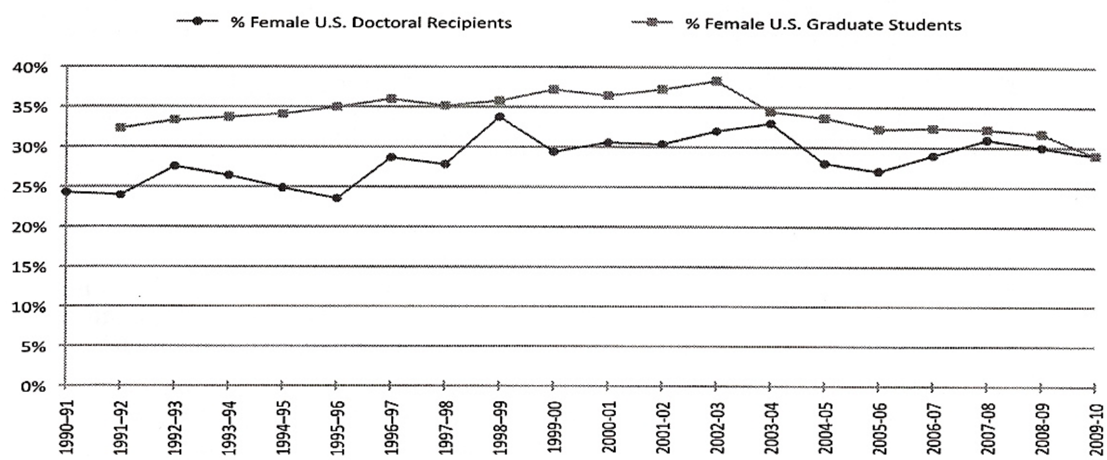
Throughout the 1790's and 80's, the percentage of women mathematics majors was steadily increasing, and it reached an all-time high of 48.3% in 1988 (Bressoud). Since then, however there has been a decrease in this percentage. There have been some brief periods of increase, however it has been decreasing slowly, reaching the lowest percentage in twenty-three years at 44% in 2007 (Bressoud). The following graph shows the gap between the number of female mathematics majors and the number of male mathematics majors.



From this graph we can see that there was a huge boom in the number of mathematics majors, both male and female, starting in the early 1980's and continuing until about 1988 (Bressoud). After reaching a high in 1988, there was a steady decline in the number of mathematics majors, until the numbers started rising again in 2001 (Bressoud). The number of male and female mathematics majors began to rise again, however the number of males increased at a higher rate (Bressoud). Bressoud found that the number of mathematics majors was declining between 2000 and 2005 in all departments except at research, or doctoral-granting, universities where the numbers have significantly increased (Bressoud). However, statistically there tend to be significantly less women at research universities than at other universities, providing a possible explanation of why the number of female mathematics majors was rising at a slower rate than the number of males (Bressoud).

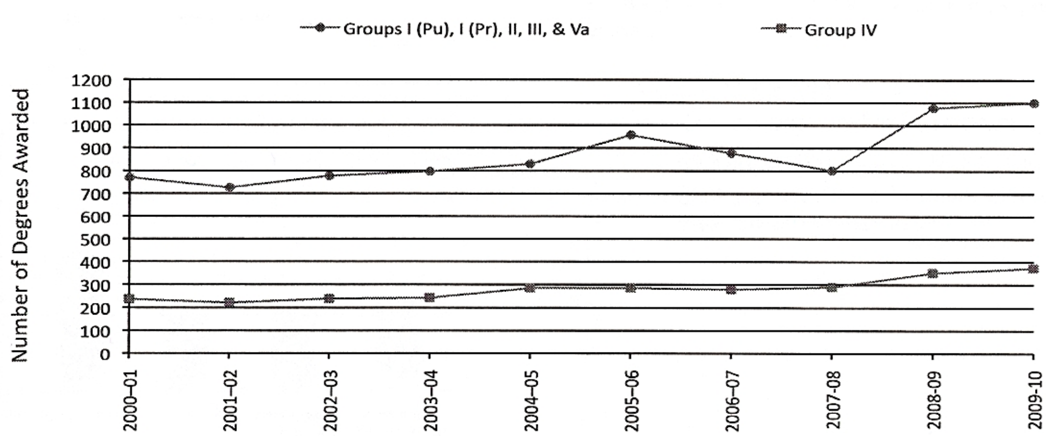
In February of this year, the 2009-2010 preliminary report on the new doctoral recipients was published in the Notices of the AMS. This is the most recent data that has been published relating to these topics. Data presented in this report shows that the percentage of female doctoral recipients has been slowly decreasing since 2003 (Cleary 296). There were a few years that the percentages stayed about the same, but the general trend was a decrease. The following graph from the 2010 Annual Survey of the Mathematical Sciences represents the declining trend.

Figure F.2: Females as a Percentage of U.S. Citizen Doctoral Recipients



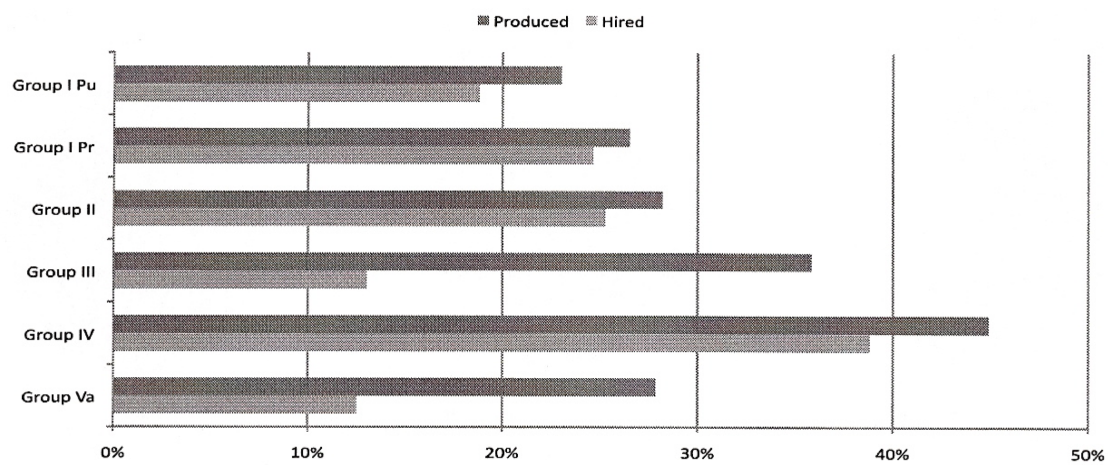
However, despite this declining trend in the percentage of female doctoral recipients, the total number of doctoral recipients has been generally increasing. This data coincides with the data that Bressoud found, and provides more support for his theory that the number of doctoral recipients was increasing mainly at research universities, where there tend to be more male students. In spite of the drop in new doctoral recipients between 2005 and 2008, the total number of doctoral recipients has increased significantly since 2003 (Cleary 292).

Figure A.2: New Doctoral Degrees Awarded by Combined Groups, Preliminary Counts



Another interesting graph from the 2010 Annual Survey shows the percentage of females hired in certain departments compared to the percentage of women that actually received their doctoral degrees in these departments. The groups represented in this graph are the same as the groups from the 2003 Annual Survey, except group IV is now represented in this graph. Group IV is made up of United States departments with doctoral programs in statistics, biostatistics, and biometrics (Cleary 298).

Figure F.1: Females as a Percentage of New Doctoral Recipients Produced and Hired by Doctoral-Granting Department



Perhaps the most interesting thing to note from this graph is the percentages for Group III, which is made up of departments with scores below 2.00 in ranking of program faculty and a few schools that were not ranked at all. Of those that graduate from these departments with their doctoral degree, a very low percentage obtains employment. The percentage of women hired is actually less than half the percentage of women that graduated. According to this data, it appears that it is important to employers what university issues your degree. One can conclude that not all doctoral degrees are viewed as equal; it is better to get your doctorate from a higher ranked school than a lower ranked school. Another interesting statistic is the percentage of women hired in the applied mathematics field. Again, the percentage of women hired from this department is less than half the percentage of women that graduated. I cannot help but wonder why this is the case. Are there fewer jobs available in this field? Or are women not as desirable in this field? Because there are no statistics for the percentage of men hired from this department, it is hard to draw conclusions on this. This would be an interesting topic for further research. It is certainly fascinating to note, however, that despite these low percentages of employed women, the unemployment rate for women in mathematics was lower than men's, as reported in this survey (Cleary 296). Based on the information from the 2010 Annual Survey, overall unemployment was at a rate of 9.9%, with the rate for women at 8.9% versus the rate for men at 10.4% (Cleary 296).

These surveys provide the American Mathematical Society with the most up-to-date information on the mathematical sciences. The field demographics are constantly changing, as can be seen from the data in these surveys. I strongly believe that things are looking up for women in the mathematics field. There are more discussions surrounding women in this field and that contributes to the increased morale of women when it comes to picking a career field. However, there is still much more to be done. In an article titled "Women Count, Everybody Counts" in MAA Focus, the newsletter of the Mathematical Association of America, Elizabeth Yanik stresses the importance of outreach programs that encourage not only women but underrepresented populations as well to pursue degrees in mathematics (Yanik 25). Yanik references David Bressoud's article mentioned earlier to further the argument that although things have improved, women still need outreach programs and added encouragement to pursue mathematics as a career (Yanik).

In the April issue of *The American Mathematical Monthly*, Susan Jane Colley wrote a review of a book written by Stephen J. Ceci and Wendy M. Williams titled *The Mathematics of Sex: How Biology and Society Conspire to Limit Talented Women and Girls*. In this review, Colley starts by stating a few interesting facts: women earn less than a third of the doctoral degrees in mathematics, and they make up an even smaller portion of the faculty at top research universities (Colley 379). She writes that it is clear from Ceci and Williams' book that there are differences between the scores of males and females on the mathematical sections of tests used to measure mathematical ability, such as the SAT and GRE (Colley 380). Although Ceci and Williams studied the effects of sex differences in spatial abilities, environmental influences and discrimination on mathematical achievement, they were not completely convinced that any of these had a major influence on the underrepresentation of women in careers in mathematics (Colley 380-381). They believe that the main influence on these statistics is women's personal preference to pursue a career that is not mathematically concentrated, although they acknowledge that personal preference is not completely impervious to external influences (Colley 381). Despite all this research, however, there is still no definitive answer to the frequently asked question of why there are fewer women in mathematics careers.

Through my interviews with professors here in the Claremont Colleges, I learned a lot about the difficulties that women in the mathematics field have had to face. I interviewed professors who graduated with their degrees in the 1960's all the way through the 2000's. The different experiences these professors have had show the improvements that have come about for women in this field. I realized that the earlier the professors went to school, the more discrimination they faced. Some of the professors who received their degrees during the 1980's and before experienced things that women should never have to deal with, especially in a professional setting such as college and graduate school. Some experiences were completely shocking. For example, nowadays if a professor tried to persuade a female student to go out with him, the backfire would be enormous. Although the younger professors realize and acknowledge that mathematics is still a male dominated field and there is still a certain degree of discrimination against women, they have in general had more positive experiences. Despite their differences though, all of the professors I interviewed believe that there is still a need for change in the mathematics field.

In 1991 the Mathematical Association of America published a book titled *Winning Women Into Mathematics*. The beginning of the book starts off with a list of Goals for the 1990's set by the Committee of Participation of Women (Kenschaft and Keith ix). It is interesting to look at the goals set up in the 1990's, and compare them with the progress that has been made since then. The goals were listed as follows:

- Increase public appreciation of the role of women in mathematics, their achievements and problems,
- Increase public awareness, especially among parents, teachers, and counselors, of the advantages of mathematics-related careers for women,
- Increase the national commitment to supporting mathematical education for girls and women,
- Increase the number, not just the percentage, of American women earning a Ph.D. in the mathematical sciences, and of those

achieving advanced academic ranks and other high-prestige positions,

- Increase the number of women mathematical professionals of all types,
- Increase the percentage of women among MAA members, officers, editors, authors, committee members, and presenters of both invited talks and contributed papers,
- Increase support services for minority women and others with special needs,
- Decrease both macro- and micro-inequities that women experience,
- Investigate the special challenges women face and explore their solutions,
- Make more information available for those wanting to help women fulfill their potential in mathematics. (Kenschaft and Keith ix)

There have been incredible strides taken when it comes to the conditions for women in the mathematics field. However, while all of the goals listed by Kenschaft and Keith have been addressed at some point, none of them have been completely achieved. This list of goals is still very pertinent to the situation for women in the mathematics field today. Whether it has to do with the two-bodied problem, having children, or just simply empowering women to rise above the stereotypes, all the professors I interviewed as well as all the articles and books I read agree that although much progress has been made, there is still a long way to go to reach equality for women in the field of mathematics.

References

Adair, Ginny. "Hypatia." *Biographies of Women Mathematicians*. Agnes Scott College, Dec. 1995. Web. 22 Apr. 2011. <http://www.agnesscott.edu/lriddle/women/hypatia.htm>.

"Annual Survey of the Mathematical Sciences." *American Mathematical Society*. American Mathematical Society, 2011. Web. 17 Apr. 2011. <http://www.ams.org/profession/data/annual-survey/survey-reports>.

Beal, Susan. "Sofya Korvin-Krukovskaya Kovalevskaya." *Notable Women in Mathematics: A Biographical Dictionary*. Ed. Charlene Morrow and Teri Perl. Westport, CT: Greenwood, 1998. 102-07.

Boaler, Jo. *What's Math Got to Do with It?: Helping Children Learn to Love Their Most Hated Subject - And Why It's Important for America*. New York: Viking Penguin, 2008.

Bressoud, David. "We Are Losing Women from Mathematics." *MAA Launchings*. Mathematical Association of America, Sept. 2009. Web. 21 Apr. 2011. <http://www.maa.org/columns/launchings/launchings_09_09.html>.

Carr, Shannon. "Mary Ellen Rudin." *Biographies of Women Mathematicians*. Agnes Scott College, June 1997. Web. 22 Apr. 2011. <http://www.agnesscott.edu/lriddle/women/rudin.htm>.

Ceci, Stephen J., and Wendy M. Williams. *The Mathematics Of Sex: How Biology and Society Conspire to Limit Talented Women and Girls*. New York: Oxford UP, 2010.

Cleary, Richard, James W. Maxwell, and Colleen Rose. "Preliminary Report on the 2009-2010 New Doctoral Recipients." *Notices of the AMS* 58.2 (2011): 291-99.

Colley, Susan J., and Jeffrey Nunemacher. Rev. of *The Mathematics of Sex: How Biology and Society Conspire to Limit Talented Women and Girls. By Stephen J. Ceci and Wendy M. Williams*. *The American Mathematical Monthly* 118.4 (2011): 379-82.

Fennema, Elizabeth. "Sex-Related Differences in Mathematics Achievement: Where and Why." *Women and the Mathematical Mystique*. Ed. Lynn H. Fox, Linda Brody, and Dianne Tobin. Baltimore: The Johns Hopkinds University Press, 1980. 209-221.

Flapan, Erica. Skype Interview. 11 April 2011.

Grabiner, Judith. Email Interview. 11 April 2011.

Hardin, Jo. Personal Interview. 13 April 2011.

Henrion, Claudia. "What's a Nice Girl Like You Doing in a Place Like This?" *Women in Mathematics: The Addition of Difference*. Bloomington: Indiana UP, 1997. 66-83.

Kenschaft, Patricia C., and Sandra Z. Keith, eds. *Winning Women Into Mathematics*. Washington, D.C.: Mathematical Association of America, 1991.

Kimberling, Clark. "Biography: Emmy Noether and Her Influence." *Emmy Noether: A Tribute to Her Life and Work*. Ed. James W. Brewer and Martha K. Smith. New York: Marcel Dekker, 1981. 3-61.

Kirkman, Ellen E., James W. Maxwell, and Colleen Rose. "2003 Annual Survey of the Mathematical Sciences (First Report): Report on the 2002-2003 New Doctoral Recipients Faculty Salary Survey." *Notices of the AMS* 51.2 (2004): 218-33.

Koch, Laura C. "Hypatia." *Notable Women in Mathematics: A Biographical Dictionary*. Ed. Charlene Morrow and Teri Perl. Westport, CT: Greenwood, 1998. 94-97.

Leder, Gilah C. "Gender Differences in Mathematics: An Overview." *Mathematics and Gender*. Ed. Elizabeth Fennema and Gilah C. Leder. New York: Teachers College, 1990. 10-26.

Levitt, Rena. Personal Interview. 11 April 2011.

"Mary Ellen Rudin." *More Mathematical People: Contemporary Conversations*. Ed. Donald J. Albers, Gerald L. Alexanderson, and Constance Reid. Boston: Harcourt Brace Jovanovich, 1990. 283-303.

Meyer, Margaret R. "Mary Ellen Rudin." *Notable Women in Mathematics: A Biographical Dictionary*. Ed. Charlene Morrow and Teri Perl. Westport, CT: Greenwood, 1998. 195-200.

Morrow, James. "Emmy Noether." *Notable Women in Mathematics: A Biographical Dictionary*. Ed. Charlene Morrow and Teri Perl. Westport, CT: Greenwood, 1998. 152-57.

“Notices of the American Mathematical Society." *American Mathematical Society*. American Mathematical Society. Web. 17 Apr. 2011. <http://www.ams.org/notices/about.html>.

Osen, Lynn M. "Emmy (Amalie) Noether." *Women in Mathematics*. Cambridge, MA: MIT, 1974. 141-52.

"Profiles of Women in Mathematics: About Emmy Noether." *Association for Women in Mathematics*. Association for Women in Mathematics, 2005. Web. 21 Apr. 2011. <http://www.awm-math.org/noetherbrochure/AboutNoether.html>.

Smith, Professor. Personal Interview. 11 April 2011.

Spencer, Steven J., Claudia M. Steele, and Diane M. Quinn. "Stereotype Threat and Women's Math Performance." *Journal of Experimental Social Psychology* 35.1 (1999): 4-28.

Taylor, Mandie. "Emmy Noether." *Biographies of Women Mathematicians*. Agnes Scott College, Apr. 1995. Web. 22 Apr. 2011. <http://www.agnesscott.edu/lriddle/women/noether.htm>.

Williams, Talithia. Personal Interview. 12 April 2011.

Wilson, Becky. "Sofia Kovalevskaya." *Biographies of Women Mathematicians*. Agnes Scott College, Apr. 1995. Web. 22 Apr. 2011. <http://www.agnesscott.edu/lriddle/women/kova.htm>.

Yanik, Elizabeth. "Women Count, Everybody Counts." *MAA Focus: Newsmagazine of the Mathematical Association of America* 31.1 February/March 2011: 25.