Nineteenth- and Early-Twentieth- Century Women Mathematicians: Family Influence, Education, and Professional Mentorship

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Starting from the 1970s and 1980s, an increasing number of survey books, biographical sketches and scientific biographies have been devoted to the topic of women in mathematics (Grinstein and Campbell xiii). Most of the biographical works adopt the "history of great men" mold, marking women's achievements to prove that women can make contributions to science as well (Schiebinger 314). However, it is also important to keep in mind that those examples of women's limited success in mathematics are exceptions rather than the norm. Why did they have opportunities in mathematics but not the others? What made them exceptional? As the above questions arise in different phases of a mathematical career, the following sections are organized into a brief introduction and three main sections corresponding to three stages of a life in mathematics, followed by discussion and conclusion.

Using Sophie Germain, Sofia Kovalevskaya and Emmy Noether as three main examples, this paper focuses on women mathematicians in the nineteenth and the early twentieth centuries and analyzes what special conditions have differentiated them from the majority of women in their times. Aside from the importance of personal talent and education, the two commonly discussed factors, this paper also noted the importance of family influence and professional mentorship.

1. Introduction

Before the nineteenth century, the seventeenth and the eighteenth centuries built the foundations of modern algebra, number theory, geometry and calculus. Mathematics in the nineteenth century further advanced in these areas of modern mathematics, with, for example,

Riemann in geometry, Cauchy and Weierstrass in Calculus, Galois and Abel in abstract algebra, and the great mathematician Gauss in a variety of fields. The nineteenth century also witnessed the establishment of mathematical societies, schools and journals, which made Paris, Zurich, Karlsruhe, Munich, Berlin, Dresden and other cities the mathematical centers of the time (Smith 9).

Before the 1800s, very few female mathematicians were known. Among the list of names, one must include Hypatia, Maria Gaetana Agnesi, and Emilie Marquise Du Chatelet. However, it was believed that possibly none of the women mathematicians before that time wrote anything highly original of a mathematical nature (Coolidge 25). Not until the nineteenth century did education opportunities gradually become available for women, ranging from the common school movement in the first half of the century to the development of higher education opportunities at the end of the century (Woyshner and Tai v). The nineteenth century and the early twentieth century saw the emergence of a group of pioneer women mathematicians, including Mary Somerville, Sophie Germain, Ada Lovelace, Emmy Noether, and others. They were remembered not only for their pioneer roles, but also for their works in mathematics and the lasting influence of their scientific contribution. In the twentieth century, women mathematicians were no longer exceptional, with the access to professional training and career opportunities roughly comparable to that available to men (Grinstein and Campbell xvii).

The time period from the nineteenth century to the early twentieth century is of special interest as a transition from the almost non-existence of women mathematicians to the integration of women mathematicians into the mainstream. Hence, the nineteenth and the early twentieth centuries were times when both numerous opportunities and plenty of limitations were

present for women in mathematics. What historical factors brought women mathematicians the long-waited opportunities? What limitations remained?

While acknowledging women mathematicians' high achievements at the time, this paper avoids celebrating romanticized personal stories, and instead attempts to answer what opportunities distinguished the successful few and helped them overcome the common limitations faced by all women of the time. As summarized by Schiebinger in her review of the study of women in science, there are four conceptual approaches mainly used to study the history of women in science (307). The first two approaches focus on the successful few, respectively chronicling and analyzing women's historical participation in science to prove that women do have a role in science, while the fourth approach aims at explaining women's relative absence in science. This paper brings together the different approaches, examining the common absence of women in mathematics through the lens of the exceptional women in mathematics.

Sophie Germain (1776-1831), Sofia Kovalevskaya (1850-1891) and Emmy Noether (1882-1935) were chosen to represent women mathematicians in the nineteenth and the early twentieth centuries. Sophie Germain was a French mathematician and physicist, known for her work on Fermat's Last Theorem and on the theory of elasticity, historically under the pseudonym LeBlanc. Sofia Kovalevskaya, perhaps the most important Russian female mathematician, made original contributions to analysis and differential equations during her years in Germany, though in biographies often portrayed as a talented amateur attended by Karl Weierstrass (Koblitz 20). In various sources of literature on Sofia Kovalevskaya, alternative names included Sonya Kovalevsky and Sofia Kovalevskaia. Emmy Noether, one of the major twentieth century mathematicians, was most famous for the theory of ideals in modern algebra and Noether's Theorem in physics. She was an active member of the mathematics community at the University

of Gottingen, and later immigrated to the United States due to Germany's Nazi government. The three mathematicians roughly covered the 100-year time span from the early 1800s to the 1920s, while associated with mathematical activities in France, Russia, Germany and the United States.

2. Early Interest in Mathematics

For the majority of women at the time, even to become interested in mathematics was almost impossible, since perhaps there was no chance at all to know what mathematics was. Prior to the nineteenth century, women were expected to fulfill domestic duties. Women's education aimed at making them better at the housewifery roles (Watts 146), and hence science and mathematics were not the central topics in the education designed for girls and women. Though it was not uncommon for an upper middle-class woman to be taught at home by tutors together with her brothers and sisters, very few women, if any at all, had the access to any means of formal education beyond basic secondary school, not to mention an academic education in mathematics. Thus, family influence was the crucial opportunity of developing initial interest in mathematics.

An educated and moderately wealthy family background not only meant the access to mathematics through reading, tutoring and home schooling, but also meant the financial support and the possible family understanding for exploring such an unconventional life path.

None of the three women mathematicians were of humble origin. Emmy Noether was daughter of mathematician Max Noether, who was a professor at the University of Erlangen and did important work in algebraic geometry (Dick 113). Sofia Kovalevskaya's upbringing was accompanied by her father's love of science and mathematics (Koblitz 1). Sophie Germain was born into a moderately wealthy bourgeois family that was able to financially support Sophie Germain throughout her life. The financial support from her family was essential to Germain's work in mathematics since she had no formal academic appointment and did not marry (Hill 3).

All of them were under mathematical influence of some form at home, which was an exceptional privilege for women in their times. Sophie Germain read extensively in her father's library, including *Histoire de Mathematiques* by Montucla, *Traite d'Arithmetique* by Bezout, and works of Newton and Euler (Hill 4). As often mentioned in various biographies of Sophie Germain, it was said that the legend of Archimedes inspired her fascination with mathematics (Frize 264), even though it seemed doubtful whether such event would be solely enough to account for her strong passion. Sofia Kovalevskaya studied algebra and calculus with a tutor. Though Emmy Noether received a formal secondary school education and studied French and English, Noether's interest in mathematics had to be related with her mathematician father Max Noether. She started to get involved in the mathematics department of the University of Erlangen by taking over her father's duties (McGrayne 70). Had it not been for the mathematical influence at home, the initial interest in mathematics would have been unlikely.

Family support of a mathematical career was also common among the three women mathematicians. Sofia Kovalevskaya was her father's favorite among her siblings, and her father was pleased with her intellectual curiosity and willingly approved her determination (Koblitz 20). Sophie Germain's parents initially considered a mathematical career inappropriate for her and took actions such as refusing to provide candles and heat (Frize 265). However, as Germain demonstrated persistent dedication, their parents relented. Sophie Germain was not the only one who was financially supported by her family. Emmy Noether also continued to live in the family home at Erlangen for a long time before she held any formal academic position. Without such support, Noether would have been forced to follow the standard path and work as a teacher of English and French. In each of the above three cases, the support all depended on both the

financial well-being of the family and the parents' intellectual understanding of the love of science.

3. Higher Education in Mathematics

Higher education opportunities became accessible to women starting from the late nineteenth century. France matriculated women into universities in 1861, England in 1878, Italy in 1885, and Germany in 1908 (Noether 134-135). Before then, it was questioned whether women had the equal intellectual capacity to study in universities, and many held the opinion that women's presence would negatively influence the academic life in universities. However, it was worth noticing that scientists and mathematicians generally had a more open view on this matter compared with scholars in humanities and other traditional academic fields. Thus, even though women were not allowed to matriculate formally, there were still plenty of informal means of learning available for women on an individual basis, often at the discretion of the professor.

Though the absence of higher education opportunities was often claimed to be one of the main obstacles for women in mathematics, the truly motivated ones still managed to find alternative learning opportunities. Sophie Germain was barred from attending the Ecole Polytechnique when it was newly founded in 1795, yet she took advantage of the fact that the Ecole Polytechnique offered lecture notes upon request (Frize 267). As Sophia Kovalevskaya was not permitted to attend any university in Russia, she sought opportunities in Western Europe instead and became the first female student at Heidelberg University (Koblitz 2). In 1900 when Emmy Noether was at the age of 18, the admission of women students was said to be "a measure that would over-throw all academic order" (Noether 134). However, by special permission from the faculty, she audited courses at the University of Erlangen. None of these alternative

opportunities came easily attainable for women, yet motivated determination and continuing pursuit made them available as temporary substitutes for formal education.

That being said, auditing classes and studying lecture notes could not fully substitute formal education. In addition to the mathematical subjects, a formal education also meant training in writing and the latest thinking in the academic circles. Sophie Germain never received a formal degree in mathematics throughout her life, unlike Emmy Noether and Sofia Kovalevskaya who eventually did. Though Germain was mathematically talented, her lack of formal training in writing and her lack of access to academic standards were still harmful to her publications. In 1826, when Germain published her work on elasticity, her writing was "clearly inadequate and could not be approved by the Academy" (Alic 155).

4. The Beginning of a Career: Mentorship

Education marked only the prelude to the beginning of a career in mathematics. The turning point from being a student to being a mathematician was by no means easier than the previous challenge of education. Even as a modern parallel in the 1970s, about 7-10% of the mathematics Ph.D. degrees in a given year were awarded to women, yet in any given year women only represented less than 3% of the newly hired faculty in the prestigious mathematics departments (Ernest 607). It must be natural to imagine that the transition into a professional mathematical career entailed far more significant challenges two hundred years ago in the nineteenth century.

Mentorship in one form or another proved to be of great value for women starting a career in mathematics, since the major challenges at the beginning of a career might be the lack of determination and the difficulty of getting recognition in the mainstream academic community. The names of women mathematicians were often associated with the names of their mentors, Sophie Germain with Lagrange and Gauss, Emmy Noether with Hilbert and Klein, and Sofia

Kovalevskaya with Weierstrass. As a side note, the word "mentorship" used here does not necessarily refer to the formal role of a doctoral thesis supervisor. In Germain's case, the mentorship took the form of long-term correspondence with Lagrange and Gauss, while in Noether's case her professional relation with Hilbert and Klein was of a more collaborative nature.

Even though the general public, the governments and a large percentage of the intellectual community were against the admittance of women into academia, a number of mathematicians with open minds believed academia should be merit-based, and provided encouragement for women in mathematics. The best example was Hilbert, who was named the president of the fictional "Union of Women Students" as a joke on his fiftieth birthday as the recognition of his support for women students in mathematics (McGrayne 71). One of his famous quotes went as follows, "I do not see that the sex of the candidate is an argument against her admission. After all, the senate is not a public bathhouse." Another example was Gauss's response to Germain after she revealed her female identity, "When a woman, because of her sex, our customs and prejudices, encounters infinitely more obstacles than men in familiarizing herself with knotty problems, yet overcomes these fetters and penetrates that which is most hidden, she doubtless has the most noble courage, extraordinary talent and superior genius" (Mackinnon 349). To encourage Kovalevskaya's studies, Weierstrass regularly invited Kovalevskaya and her friend Lermontova to dinner with him and his sisters, treating them as beloved daughters (Abir-Am and Outram 178). Though no primary source of the women mathematicians' inner feelings could serve as evidence here, it would be no surprise if such words helped consolidate confidence in mathematical ability and determination in pursuing equal career opportunities in mathematics.

Perhaps more tangible than emotional support was the professional support and endorsement in a mentorship relation. When Kovalevskaya was officially barred from attending his lectures during 1870-1874, Weierstrass taught her private lessons, topics including Elliptic Functions, Synthetic Geometry, Analytic Functions, and other courses (Cooke 17). In 1874, Kovalevskaya earned her doctoral degree at the Universisty of Gottingen, with Weierstrass's instrumental endorsement (Abir-Am 178). Noether held no formal academic position until she was finally appointed as a *Privatdozent* at the age of thirty-nine, albeit still unpaid. For years before the formal appointment, Hilbert listed Noether's lectures under his name and had Noether as his assistant (McGrayne 71). Klein also offered assistance by pleading to the Prussian ministry. Though not a typical case, Sophie Germain (under the pseudonym Leblanc) was introduced by Lagrange into "the inner circle of the academic elite" by correspondence, which eventually brought up Fermat's Last Theorem to her. Mentorship played an instrumental role in the mathematical careers of Kovalevskaya, Noether and Germain, especially at the point of earning a degree or a faculty appointment.

One may still wonder: under what circumstances did the young women have chances to be known by the reputed mathematicians? In most cases, such voluntary guidance was contingent on personal talent in the first place. Sophie Germain was noticed by Lagrange because of her papers under the pseudonym Leblanc (Frize 267). Kovalevskaya was recommended to Weierstrass by Konigsberger, whom she worked with at Heidelberg and gained a reputation for her talent in mathematics (Koblitz 5). Emmy Noether first met Hilbert and Klein when she visited them together with her father in 1913-1914 to write the obituary of Max Gordan. By the time she met Hilbert and Klein, she was already "an authority on invariants" (McGrayne 70) and advised Klein's projects on Einstein's general theory of relativity. Mathematical talent was the

determining factor, if not the only factor, in the start of most mathematical mentorship connections.

5. Discussion

Although later in career publishing impactful works became the key for getting recognition in the mathematics community beyond the above three stages, women in the nineteenth and the early twentieth centuries still needed more than mathematical talent alone during the earlier phases of a mathematical career. Traditionally, the lack of formal education, especially higher education, was often assumed to be one of the main reasons why the number of women mathematicians remained so low, yet a variety of alternative learning opportunities were available in the form of private lessons, correspondence, lecture notes, etc., and hence education was not the only explanation for women's relative absence in mathematics. As evident in the cases of Germain, Kovalevskaya and Noether, deciding factors included family background, the access to learning opportunities, and the guidance from more experienced mathematicians. Family background determined whether or not the atmosphere at home was encouraging and supportive for developing interest in mathematics, as well as whether or not financial concerns would be worrisome when the hope for formal academic appointment was unclear. Mentorship meanwhile provided moral support and introduction to the academic circles, and also more importantly, the essential endorsement in times of pending approval for a degree or an academic position. Despite the successful examples cited above, one could imagine that there were many more women in the nineteenth and the early twentieth centuries who were equally talented in mathematics yet had no chance to make good use of their talents.

Due to limited resources, this paper only concerns mathematicians in the specific time period from the nineteenth century to the early twentieth century. A number of studies have been

focused on contemporary women mathematicians and women mathematicians in the past century. Further results might be available if the nineteenth- and early-twentieth- century women mathematicians are compared with their counterparts in more recent times. Since different countries had different education systems and cultural values, a further survey of women mathematicians in each country (Germany, France, England, etc.) might provide additional understanding of the topic. It would also be valuable to compare the career paths of female mathematicians with that of male mathematicians, and see what kind of roles family influence and mentorship played in a mathematical career for a male mathematician.

Over the past hundred years since the early twentieth century, how much improvement has been made in these three aspects? As often celebrated by the women's rights movement and the general public, there has certainly been remarkable progress in all levels of educational opportunities in the past century, from elementary schools to universities. However, while education was not the only obstacle for women in mathematics, the family influence remained, and the challenges at the beginning of a professional career remained. Part of the reason why women's early interest in mathematics often receives negative feedback from their parents even today was the stereotype of women mathematicians and the social expectations of women. A psychology study in 1971 showed that the received image of women mathematicians was still associated with being less feminine (Helson 210). It was also worth noting that half of the creative mathematicians samples in the study had professional men as fathers, indicating the importance of the family impact. This historical study of women mathematicians is still alive today with meaningful insights into the modern career paths of women mathematicians.

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