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Career paths in mathematics: A comparison between women and men

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1 Introduction

In western industrialized countries, we can still find the stereotype that *Mathematics is not a subject for women.* This is reflected, for instance, in the number of female university professors: in many countries (we shall be focussing on Germany), the percentage of women among the university professors is very small. In order to discover the (historical and current) causes of this phenomenon, we analyzed the career paths of several thousand individuals who successfully completed their studies of mathematics at German universities during the 20th century. This paper introduces the resources and methods of our interdisciplinary research project and presents the main results obtained by comparing career paths of male and female mathematicians.

Some popular science books currently enjoying wide distribution suggest that women may be genetically predisposed to be poor at mathematics. These books—allegedly based on scientific results—serve to reinforce gender stereotypes and claim, among other things, that women have a weaker spatial sense than men due to structural differences of the brain. The argument goes that therefore women are less likely than men to choose professions that require spatial visualization skills. To see an example of this:

> Consulting history you will find that there are practically no outstanding women in areas that require good spatial visualization skills as well as mathematical thinking, as there is for example chess, composing music or rocket research. (Pease and Pease, 1998, p. 192)

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Yet, if we examine these claims, we discover that they are unverified;[1] it has not been proven that good spatial sense—however it is measured—is an essential prerequisite for mathematical talent.[2]

For the obvious historical reasons, female mathematicians are little known as role models. When we asked approximately 50 first-year students in our course at the beginning of the *Sommersemester 2008* to name three famous female mathematicians, the answers were alarming:[3] Only three students could name one female mathematician (Emmy Noether). Of course, this is not for lack of outstanding female mathematicians in the history of mathematics; it is particularly surprising since traditionally, mathematicians have regarded women with less prejudice than have researchers in other fields. As discussed by the sociologist Bettina Heintz (2003), this may be due to the fact that it is easier to objectively appraise performance in mathematics than in other research areas.

The famous Göttingen mathematician Felix Klein (1849–1925) suggested to his former doctoral student Johannes Schröder (1865–1937) that he investigate the mathematical instruction at public secondary girls' schools, after mathematics had finally been introduced in secondary schools in 1908. Schröder was a former girls' grammar school teacher in Hamburg;[4] one third of his students went on to study mathematics at universities. After interviewing colleagues, he concluded:

> In the past the prejudice persisted that women are completely lacking the talent for mathematical thinking. It was widely understood that their female characteristics would rather draw them towards an occupation with questions of Literature, Language, History and Ethics as opposed to the strictly logical reasoning associated with mathematics. Klein, among others, has shown convincingly how unjustified the presumption of mathematical thinking not being in a woman's nature is. (Schröder, 1913, p. 89)

In fact, Klein had supervised two doctoral theses written by female students by the year 1895. He knew that, on average, female mathematicians from abroad who attended his lectures had the same mathematical talent as their male co-students. Nevertheless, the old stereotype of women being less talented in technical subjects persisted for quite some time in most of the academic world, and especially in the humanities.

[1] Pease and Pease (1998, p. 166) refer to the allegedly verified surveys of the psychologists Benbow and Stanley (1983); cf. Beerman's conclusion (Beerman et al., 1992, p. 41) that this and other results of Benbow could not be verified.

[2] For the components of mathematical talent, cf. (Beerman et al., 1992, p. 15).

[3] The students were studying mathematics or some other subject at the Department of Mathematics at the *Universität des Saarlandes* in Saarbrücken.

[4] Cf. § 3.3. It was not uncommon for people with doctorates to go on to teach at secondary schools.

International statistics show that the percentage of female students studying mathematics and information technology in industrialized Western countries is smaller than in other countries. There are more female mathematics students on the Gulf peninsula and in South America than there are in Europe. In Eastern Europe, there are more women in mathematics in than in Western Europe (cf. Abele et al., 2004). Currently, Germany has one of the lowest percentages of women in mathematics. This is especially true for more senior positions in academia; the percentage of female professors in mathematics at German universities is under five percent. But what are the reasons? This question was the starting point for an extensive quantitative survey about careers in mathematics.

2 Project, methods, resources

The German *Volkswagenstiftung* supported the interdisciplinary project entitled "Women in mathematics: factors determining mathematical careers from a gender comparative perspective" initiated in 1998. We published its main results in a book with the title *Traumjob Mathematik* (Abele et al., 2004).

In our project, we followed a twofold analysis strategy: on the one hand, we collected historical and present-day data, and on the other hand we compared the historical data with the present-day data. Our objective was to analyze the careers of individuals who obtained their degree in mathematics either in the first half (historical) or at the end of the 20th century (present-day). Careers were tracked from birth to until several years after graduation using a model developed in socio-psychology due to Abele. In order to determine the factors that determine career development, we differentiated between individual-related variables (gender, origins, education and age) and external conditions (type of school system, laws).

The collection of *present-day data* is still research in progress. It deals with the careers of individuals who completed their studies in 1998. We based our research on written interviews obtained by standardised questionnaires with the most recent interview conducted in early 2008. The rate of return of questionnaires in this study was very satisfactory. Based on our experience, this indicates that people are content with their professions.

The *historiographical* research into careers in the first half of the 20th century has almost been concluded. In that time period, studies of mathematics could be completed by passing either a teachers examination or a doctoral examination; a *Diplom* in mathematics was not common before 1942. However, as early as 1920, it was possible to take a *Diplom* examination in mathematics at technical universities—but the number of graduates was low (less than 100 until 1945). We analyzed the career paths of two representative groups of people:

1. Individuals who had graduated from a teacher's course in mathematics, 1902–1940

2. Individuals who earned a doctorate in mathematics, 1907–1945

The research on the first group was based on newly discovered material from the Archive for Historical Education Research in Berlin. Over 100 boxes of personnel record cards of Prussian teachers dating from the beginning of the 19th century have been preserved; they are sorted alphabetically. We opened every third box and selected those individuals who passed their teacher examinations in mathematics.[5] We analyzed the personal records of 3,040 Prussian mathematics teachers who completed their examinations between 1902 and 1940; 462 (15.2%) of them are women.

In the second group, we considered every person who earned his or her doctorate in the reference period of these records. In 2006, we published a second book containing the short biographies of these individuals (cf. Tobies, 2006). In the course of our research, we succeeded in revealing biographical data of many formerly unknown mathematicians; among them doctoral students of Emmy Noether.

As a side effect of our research, we were able to shed more light on the position of Emmy Noether in the mathematical community. In 1998, the German mathematician Friedrich Hirzebruch stated in an interview, that "Emmy Noether did not have a school" (published as Hirzebruch, 2000, p. 1230). Our research contradicted this statement, and in response, we published the article (Koreuber and Tobies, 2002). Independently, Hirzebruch Hirzebruch (1999, p. 58) had come to the same conclusion.

We also discovered previously unknown female mathematicians who had followed job offers abroad; one of them was Cäcilie Fröhlich (Cecilie Froehlich) (1900–1992). She completed her doctorate in mathematics at the University of Bonn and became a researcher in applied mathematics at the power company *Allgemeine Elektrizitätsgesellschaft* (AEG) in Berlin. Fröhlich's career is a significant illustration of the fact that women followed careers in industrial research as early as the 1920s. However, she was Jewish and, therefore, was dismissed from her position in 1937. Even so, the AEG board provided her with an excellent certificate and she subsequently gained a position as a mathematical consultant in one of the most important power companies in Belgium (*Atelier de Constructions Électriques de Charleroi*). In 1940, she was forced to emigrate again and, finally, became a professor of applied mathematics in the electrical engineering department of the City College New York.

In Germany, the year 2008 was dedicated to mathematics as the *Jahr der Mathematik*. The *Deutsche Mathematiker-Vereinigung* celebrated the occa-

[5] Beginning with 1880 as a year of birth and continuing onwards from there.

sion, in part, by posting our short biographies of mathematicians on their web page. This source contains all men and women from Germany and foreign countries who completed their doctorates in mathematics at German universities from *Wintersemester 1907/08* to *Wintersemester 1944/45*, including information about their membership in the *Deutsche Mathematiker-Vereinigung*. Fröhlich's short biography can be found there.

3 Career paths of male and female mathematicians, 1900–1945: A comparison

The distribution of exams over the years clearly reflects historical context (e.g., World War I, or the congestion of schools in the mid 1920s). Our sample covering more than a third of the overall population according to Prussian statistic almanacs is representative. The distribution of doctoral degrees is similar to the distribution of the teacher examinations. Most of the graduates who earned a doctorate in mathematics also completed a teacher examination. The ratio of men and women is equal (slightly over 20%) among those individuals with successful teacher examinations who continued to pursue doctorates, though not all doctorates were in mathematics. Of all new graduates with doctorates in mathematics before 1945, only 8% were female.

Of course, there were female mathematicians earning doctorates in Germany before 1907, the beginning date for our research period; they were mostly foreign and their ambition paved the way for German women to follow suit. The first female doctor of mathematics was the Russian Sofja Kowalewskaja (1850–1891); she was awarded her degree in 1874 at the University of Göttingen and would continue her career as a mathematics professor in Stockholm. However, it would be 21 years before the next doctorate in mathematics was awarded to a woman in Germany; in 1895, Marie Gernet (supervisor: Leo Königsberger) at the University of Heidelberg, and the British Grace Chisholm (supervisor: Felix Klein) at the University of Göttingen both earned doctorates.[6]

3.1 External Conditions

Education dependent on secondary school types.

In 1908, courses in mathematics and natural sciences were offered for the first time at public secondary schools in the Kingdom of Prussia, Germany's biggest constituent state (capital: Berlin). Before the general introduction of these subjects, girls and women could acquire related knowledge in private courses only. The Kingdom of Bavaria (capital: Munich) followed suit in 1910.

[6] About the first foreign women who completed a doctorate in mathematics at a German university, cf. Tobies (1999) and Abele et al. (2004, Chapter 7.1).

1874. First woman to earn a doctorate in mathematics at a German university (with exemption).

1900. Permission for women to enroll at universities in the Grand Duchy of Baden.

1903. Permission for women to enroll at universities in the Kingdom of Bavaria.

1905. First woman to complete her teacher examination in mathematics (Berlin, Prussia)

1908. Permission for women to enroll at universities in the Kingdom of Prussia.

1909. Permission for women to enroll at universities in the Grand Duchy of Mecklenburg.

1919. At least until 1919, female teachers (like all state officials) had to be celibate.

1920 A law (21 February) permitted women to receive the *venia legendi* (Habilitation). In 1919, Emmy Noether already took this hurdle with exemption as the first female mathematician.

Until 1945. Only two women appointed to full professorships at German universities, none in mathematics, none of them in Prussia.

FIGURE 1. Historical overview of legal regulations.

There were four different types of secondary schools in Prussia: *Realgymnasien*, *Humanistische Gymnasien*, *Oberrealschulen* and *Oberlyzeen*. It is remarkable that most of the women in our sample completed their studies at a *Realgymnasium*. This type of school offered more lessons in mathematics and natural sciences than the *Humanistisches Gymnasium* that boys tended to attend. In the Prussian statistic yearbooks, we can find the ratio between different types of schools for girls, i.e., *Realgymnasien*, *Humanistische Gymnasien*, and *Oberrealschulen*. *Oberlyzeen* did not teach girls any mathematics or natural science.

Legal Regulations.

Legal regulations excluded women from academic studies and careers for a long time (cf. Figure 1 for an overview). In Germany, foreign women were the first ones to earn a doctorate, though they could only do so by exemption. The general acceptance of women for regular enrollment, teacher examinations, and postdoctoral lecture qualifications (*Habilitation* and *venia legendi*) was introduced much later in Germany than in other countries.

As a consequence of these legal regulations, only two women received a full professorship before 1945, one in the education studies at the University of Jena (Thuringia), and one in plant physiology at the *Landwirtschaftliche Hochschule Hohenheim* in Stuttgart (Württemberg). Moreover, until 1919, the law of celibacy forced salaried female teachers to resign from their tenure

Social background	Profession of fathers (female mathematicians)	Profession of fathers (male mathematicians)
Primary or secondary education	26.7%	20.4%
Academic education	32.0%	24.5%
Trading & business	17.2%	27.5%
Mid-level and senior civil servants	17.2%	21.3%
Military Staff	5.2%	1.3%
Working class	1.7%	4.0%

FIGURE 2. Social background of women and men who obtained their doctorate in Mathematics, 1907–1945. "Primary and secondary education" includes both teachers and education authorities. "Mid-level and senior civil servants" includes municipal, bank, post, and railway services.

upon marriage.

As soon as women were accepted for regular enrollment, mathematics evolved into a very popular field of study. The percentage of first-year female students was higher than the overall share of the female students in the 1920s. However, this changed under the Nazi dictatorship.

3.2 Personal Variables

The women covered by our sample were more likely than the men to have academically educated fathers (cf. Figure 2). Since the educations of daughters were typically funded by the parents, a studying daughter required family wealth; in contrast, sons were often allowed to study even if their families were less well off.

In our sample, the percentage of women with a Catholic confessional background (36%) is higher than the percentage of men (25.9%) and also higher than in the general population. This fact is primarily due to regional differences; Catholic areas with universities, such as Münster, Breslau, and Bonn, provided early favourable environments to women than did other places. There were several Jewish women who completed their doctorate in the first years of the 20th century and became famous researchers (e.g., Emmy Noether, Cäcilie Fröhlich) or teachers at secondary schools. Noether and Fröhlich would later emigrate but most of the secondary school teachers did not succeed in emigrating and suffered a terrible fate (cf. Tobies, 2006).

At the time of passing the teacher state examination (women $N = 462$, Men $N = 2578$), the average age of women was 27.14 years whereas the average age of men was 25.85 years. The fact that women were slightly older, corresponds to the fact that women had regularly been teaching at primary schools or medium-level secondary girls' schools before they enrolled at university.

	Women	Men
N	381	1864
Average final grade	2.17	2.21

FIGURE 3. Average final grades of teacher state examination in the years 1902–1940. The range of grades was "with distinction" (counted as 0.75), "*sehr gut*" (very good) (1.0), "*gut*" (good) (2.0), "*befriedigend*" (satisfactory) (3.0), and "*ausreichend*" (sufficient) (4.0).

3.3 Study Processes

Number of subjects in which men and women with mathematics as a main subject completed their state teacher examination

Most individuals in our sample passed their state teacher examination in three subjects without any gender difference.

Preferred Combination of subjects in the Teacher Examination

Women, like men, opted for the combination of mathematics, physics, and chemistry without any gender differences.

Universities and technical Colleges awarding doctoral degrees in mathematics, 1907–1945

The mathematicians in our sample obtained their doctorates from 23 different universities and twelve technical colleges. Based on the data, we can make the following observations:

- Göttingen was an international centre for mathematics until 1933.
- Bonn offered a particularly friendly climate for women.
- Technical colleges received the right to award doctorates later than the universities.
- At the Technical college of Dresden women were employed early and often for many years as mathematical assistants.

Teacher state examinations in mathematics: Overview of final grades

The final grades in the state teacher examinations listed in Figure 3 do not show any significant difference between men and women. Additionally, we tested a representative sample of grades for oral doctorate examinations; our findings suggest that this also holds for average grades for doctorate degrees.

Distribution of doctoral theses in mathematical subfields, men and women by comparison, 1907–1945

An older U.S. survey that compares doctoral theses awarded to men and women (from the time they were first issued until 1940) (cf. Green and LaDuke, 1987 and 2009) states that women, more often than men, wrote their dissertations in traditional fields like geometry whereas men's dissertations were more often in analysis. For instance, between 1930 and 1939, 39% of women wrote dissertations in geometry and only 25% in analysis; for men, the figures are 27% and 42% respectively.

This trend is not seen in Germany, as Figure 4 shows. Instead, the focus of research generally moved in the course of time. Until 1915, geometry was favoured by both men and women; in the following years, geometry and analysis have been chosen with equal frequency. Furthermore, the importance of applied mathematics in fields such as natural science, technology and engineering, finance and insurance mathematics, and statistics has necessitated an increase in graphical and numerical methods as well. Since 1934, the number of doctorates in applied mathematics has been equal to the amount of doctoral theses in geometry and analysis.

Generally, according to our data, there was no significant gender difference in the choice of subfield. The only significant difference that could be found was in applied mathematics; however, this difference can be explained as follows: the field of applied mathematics was expanding in the period after 1930, but it was in that period that the number of female mathematicians earning doctorates was in decline in general. We should like to emphasize, though, that a number of female mathematicians produced outstanding results in applied mathematics in such fields as aviation research, bio-statistics, and electrical engineering after they had written a thesis in one of the other fields of mathematics.

It has been a matter of debate among mathematicians and philosophers of mathematics whether you can classify mathematicians into several well-defined *types*. According to a particularly famous account, there is the *mathematical philosopher* who works from terms and concepts, the *analyst* who works with formulas, and the *geometer* who reaches new conclusions based on visualizations.[7] Our results show that differences in research style are not correlated with gender; academic work in a certain mathematical subfield employing specific methods is a result of individual education and affiliation with a particular school of thought.

[7]This debate was started in connection with a professorial appointment process in the year of 1892 and exclusively referred to men; in the debate, some famous mathematicians were classified according to these three types. The conceptual thinking approach has been largely attributed to Richard Dedekind and Georg Cantor. However, Emmy Noether and her students subsequently worked in the same fashion.

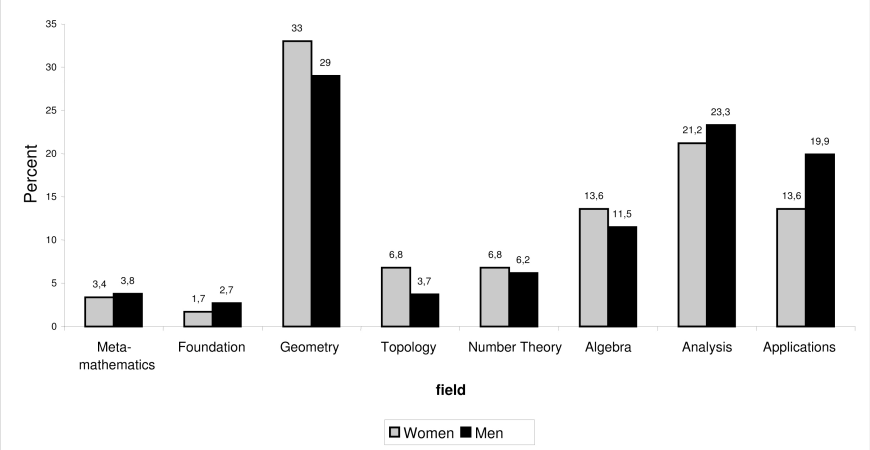

FIGURE 4. Distribution of doctoral theses in mathematical subfields at German universities, 1907–1945

Before the 1930s, secondary school teaching was the most common career path for mathematicians, even those with doctorates; this changed, however, when the world-wide economic crisis caused a hiring freeze in secondary schools. At the same time, mathematically educated people were widely recruited and promoted by the business and military industrial complex in connection with the war effort; significant examples are the aircraft industry and aviation research. Here also women found employment—for example, in rocket research, where we discovered a number of outstanding female scientists.

Here, Irmgard Flügge-Lotz (1903–1974) and Ingeborg Ginzel (1904–1966) were important pioneers (cf. Tobies, 2008); they were awarded doctorates at the end of the 1920s at the *Technischen Hochschulen* in Hannover and Dresden, respectively. After that, they worked in aviation research at the *Aerodynamische Versuchsanstalt* in Göttingen. Immediately after the war, it was not possible to continue in aviation research in Germany, so they continued their careers abroad, as did many of their male colleagues. Flügge-Lotz went to Stanford University via France and Ginzel went to the U.S. aircraft industry via the United Kingdom. Ginzel worked with the company that manufactured the bombs dropped on Nagasaki and Hiroshima, one of the largest companies in the U.S. market. This clearly demonstrates that women are not antimilitaristic by nature, just as they cannot be said to be predisposed to specific characteristics or have specific academic subject preferences.

4 Historical and present-day careers: A comparison

Women historically favoured mathematics as a subject of study and they still do. Women currently represent over 50% of those studying mathematics for a teaching profession. In Germany, women studying mathematics generally become teachers. Decisions of this type are often related to the fact that a state school teaching post allows the combination of a professional career and family life in a way that is impossible when working for a private employer. Women account for approximately 40% of those enrolled in *Diplom* programmes.

In summary, our main findings are that historically, the socioeconomic background of female students was distinctly different from that of male students; today that is no longer the case. The career entry for men and women was and still is similar. In the early 20th century, there as a great deal of legal discrimination against women in mathematics; today the main challenge that women face is balancing career and family life. Neither historically nor presently, we can find any gender-related differences in performance parameters such as final degrees or duration of study. However, differences do exist between students studying to become teachers and those studying to receive the *Diplom* degree. On average, *Diplom* students earn higher grades but study longer. Female students pursuing teaching positions are the fastest to finish their studies; a random sample of historical data shows an average length of study of nine semesters. In the past, studies were finished considerably faster, even though the place of study was changed more often and examinations were normally taken in three subjects.

Upon beginning a career, there is no difference between men and women; even three years after their exams, there are no significant disparities. Over 50% of the individuals that passed the teacher examination are now working in their profession; others are still in training. Of those who are unemployed, 44% are mothers.

Shortly after their examinations, there is no gender disparity among *Diplom* graduates either; currently, most find employment regardless of gender if they leave academia after the *Diplom* degree. Among doctoral students, there is no gender disparity in the number of total years spent at the university. Five years after graduation, men and women have the same likelihood (13%) of having reached the status of supervisor with at least six employees under them. However, this is not true of women who have become mothers.

In conclusion, we can stress that the successful integration of personal and professional life is an important component to personal satisfaction.

5 Concluding remarks

Before 1945, there was no difference in the career paths of women and men up to the position of a *Studienassessor*. Due to the legal situation, in order to obtain higher positions, women had to choose career over family. Today, female mathematicians without children reach the same positions and salaries as their male colleagues. At the same time, there is a great disparity if we consider the total number of women in senior positions in mathematics.

This raises the following natural questions: What are the causes of this disparity? There is a great number of female students and graduates, but where do they go and why? (In mathematics as in the humanities the vast majority of full professorships are held by men.) Are women generally less career-oriented than men? Is this related to the decision making process for hiring of professors? Who is part of this process and how do they affect it? What are the current options of combining career and family? Is the decision against children that we observe in many of the successful female mathematicians a consequence of an internalized "uncaring mother" prejudice? (This seems to be a specifically German concern.)

Still, women are more likely than men to end, freeze or slow down their careers for the benefit of their families. In 2006, 89.3% of interviewed female mathematicians reduced their professional engagement in favour of children, for men it was only 28.45%. Our results show that men are, in general, more career-oriented than women. There is a strong correlation between career-orientation before graduation and success in the profession after graduation.

A large number of the interviewed women prefer a so-called *soft career*, which includes family phases (marriage, children, etc.) from the outset. As a consequence, in Germany, academically educated women regularly stay home for a considerable time after giving birth. On one hand this is due to insufficient child care facilities, on the other hand, the so-called "uncaring mother" argument looms ever-presently in the backs of minds. Very importantly, the interviews revealed that many women perceive slow professional advancement as a sign of having successfully integrated family and professional life.

It is beyond doubt that science as a whole is suffering if talented researchers are not doing research. Many excellent female mathematicians decide to quit research after the doctorate. Among other reasons, they name the required mobility for junior researcher that is a necessity for a scientific career in Germany. So, in order to increase the number of women achieving leading positions in mathematics, we must work on the integration of career and family and raise the awareness among female researchers that careers in research are possible, can, and have to be planned.

1988. *Abitur*, Frankenthal (Pfalz).

Studies of mathematics with minor in business studies at the University of Kaiserslautern.

1994. *Diplom* in mathematics.

1998. Doctorate in mathematics (Kaiserslautern).

2003. *Habilitation* (Kaiserslautern) 2003.

2004. Professorship (W2) at the Institute for Numerical and Applied Mathematics, University of Göttingen.

FIGURE 5. Career milestones of Prof. Dr. Anita Schöbel

In fact, there are already good role models available who exemplify how women can integrate a professional and personal life; one is Anita Schöbel who is married with two children. In Figure 5 is a list of her career milestones. The successive longitudinal study will clarify whether the 21st century will produce more successful examples like Professor Schöbel.

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