INTRODUCTION

WOMEN RESEARCHERS IN INDUSTRIAL LABORATORIES: TRENDS AND PERSPECTIVES

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Our primary aim in this introduction is to formulate a number of theses regarding the factors and parameters that determined the careers of women in industrial laboratories during the first decades of the twentieth century. These theses derive from our own long-standing investigations about female scientists and female researchers and their career paths,[1] on the chapters written by our colleagues in this book, and on the many discussions that this collaboration incited. Here we would like to describe the trends of this relatively new research field, to analyze its development, and to enumerate some of the overarching issues that have informed this book and that will prove relevant to further studies. The following theses can be thought of as a summary of *Women in Industrial Research*, and we hope that they might also serve to instigate discussions in the future.

Thesis 1

Approximately from the year 1900 onwards, equal access to education at all school and university levels and access to academic careers were preconditions that enabled women to join industrial research laboratories.

In countries where access to educational institutions, especially to universities, was less dependent on state regulations, some female scientists were able to obtain positions in engineering and industrial research laboratories. Based on international comparisons, Ilse Costas developed an explanatory model for women's access to *academic* careers.[2] For careers in *industrial laboratories*, our investigations have confirmed that the preconditions in these fields were similar. In the United States and Great Britain, for instance, women had (easier) access to uni-

1 See TOBIES 1997, 2006, 2008, 2013; VOGT 2000a, 2000b, 2007, 2008.
2 See COSTAS 2002, 2003.

versity educations somewhat earlier than in Germany, and thus a few female scientists were able to contribute to industrial firms there relatively earlier. Here we can mention, by way of example, Hertha Marks Ayrton, who in 1899 became the first female member of the British Institution of Electrical Engineers, and the American Edith Clarke, who began her career at the American Telephone and Telegraph Company in 1912. Both were able to develop important devices and won awards for their work (see the Introduction to Part II). The German-American Lillian Moller Gilbreth, moreover, is an interesting example of a women researcher who established her own successful company in the United States. Lillian and her husband, Frank Gilbreth, founded the Gilbreth Consulting Firm, which approached ergonomics and industrial efficiency on a scientific basis. Their studies helped to improve productivity at several corporations, and Lillian Gilbreth went on to work as a consultant for five American presidents. She also served as a role model for Irene M. Witte in Germany, a female expert in scientific management (see Chapter 4).[3]

It was often the case that foreign women scientists and researchers became role models for German women. This is also true regarding women's access to university studies. Women students from Russia, the United States, and Great Britain had opened the way for women students from Germany to study at German universities and to obtain university degrees. In fact, women students from abroad were the first women to receive doctoral degrees from German universities. The Russian Sofia Kovalevskaya earned a doctoral degree in mathematics at the University of Göttingen as early as 1874 (the first German woman did so in 1895); the Russian Julia Lermontova completed her doctorate in chemistry at the same university in the same year[4]; in 1895, the American Margaret E. Maltby became the first women to obtain a doctoral degree in physics at a German university, and she did so at the most famous international center of mathematics and science at the time, namely the University of Göttingen.[5] Exceptional conditions and circumstances were required for these female students to earn doctoral degrees, for it was not until 1909 that all the federal states of Germany (beginning with Baden in 1900) officially opened their universities and technical universities to women students.[6]

3 See, for example Frank Bunker Gilbreth and Lillian Moller Gilbreth, *Applied Motion Study: A Collection of Papers On the Efficient Method to Industrial Preparedness* (New York: Sturgis & Walton, 1917), a German edition of which appeared in 1922. See also POKORNY 2003.

4 See TOLLMIEN 1997. On Kovalevskaya, see HIBNER-KOBLITZ 1983.

5 On American women in German speaking countries, see SINGER 2003. On the first American female doctoral student at the University of Jena, see Chapter 10 of this book.

6 See Table 1 in TOBIES 2012, p. 6. On the special case of Berlin, see also VOGT 2004, 2007. At the time, Berlin had two institutions of higher education, the University of Berlin, which was founded in 1810, and the Technische Hochschule Berlin-Charlottenburg, which was a technical university. Later, most of the German "Technische Hochschulen" changed their names to "Technische Universitäten" for the sake of international compatibility. Throughout this book, we use the term "technical university" to designate both institutions.

Thesis 2

For a long time, female students who received a doctoral degree in mathematics, physics, or chemistry preferred teaching jobs at secondary schools. Being a teacher was an acceptable profession for young women at the time in most European countries, including Germany. Only a few qualified female specialists, especially those with interdisciplinary training, ventured to apply for positions at industrial laboratories.

When, after extensive debates and struggles, German universities finally opened their doors to female students, the curricula at girls' secondary schools were accordingly reformed and supplemented. The girls' schools were then in need of female teachers, especially of mathematics and the sciences. At the same time, the first female students who had studied regularly at German universities were completing their studies and receiving academic degrees. The job opportunities for them in newly reformed or opened schools were therefore relatively good, at least until the late 1920s. In Germany, moreover, the teaching profession was considered to be quite respectable. Female physicians and female teachers were the first to be welcomed and acknowledged by the German Empire, and thus it is no surprise that the first women scientists to complete their studies sought employment in schools before attempting to find positions in academic or non-academic research institutions. The opportunity to become a teacher offered a degree of security in an otherwise uncertain job market. This was true both for male and female scientists, but such security was especially important for female scientists, whose opportunities were relatively limited.

This thesis is supported by a prosopographical study that was funded by the German Volkswagen Foundation.[7] In it, we analyzed the careers of more than three thousand male and female students who, from 1902 to 1940, had successfully completed their studies of mathematics and two other scientific disciplines at German universities, and who had also become certified to teach at secondary schools. Of this group, 15.2 percent were women. Approximately twenty percent of our sample of 3,040 teachers had obtained a doctoral degree in mathematics, physics, or another scientific discipline. Interestingly, this same percentage applied to both men and women alike. Teaching examinations required expertise in at least three different disciplines, and the combination of mathematics, physics, and chemistry was the most preferred by both male and female students at the time. Most of these students, including those who received a doctoral degree, became school teachers, typically in secondary schools. Our study also included a detailed analysis of the career paths of those who had completed a doctorate in mathematics from 1907 to 1945. Of these, only 3.6 percent of the men and 3.4 percent of the women went on to work in industry. Although sources concerning

7 See ABELE/NEUNZERT/TOBIES 2004. Surveys of the results are published in English in TOBIES 2011, 2012a.

the history of industrial laboratories are often obscure or lacking, we can assume that these percentages correspond somewhat accurately to the actual situation.

We should add that the *Diplom* degree (which corresponds to a master's degree) in mathematics and physics was not generally offered at German universities before 1942. Its purpose was to shorten the time of university study on account of the war, which the Nazis had just begun. For chemistry, however, the *Diplom* degree was introduced as early as the last third of the nineteenth century, much like the *Diplom-Ingenieur* degree that German technical universities had been offering since the 1870s. The first female engineer to earn a *Diplom* did so in 1913 at the Technical University of Darmstadt; it was such a notable event that the newspapers reported about it.[8] Because of an abundance of students who studied chemistry, more scientifically trained men and women were able to achieve positions in the chemical industry, at least at first, than in others. On the nature of these positions, see Theses 3 and 5 below and Chapter 7.

A gender-based quantitative study of the careers of physicists has yet to be conducted.[9] Having studied the career paths of industrial researchers during the first three decades of the twentieth century, we discovered that the total number of male and female researchers with university degrees was relatively small, and thus the number of female researchers with such credentials was even smaller. Our discussion is therefore limited to a small sample of industrial researchers and to the small cluster of laboratories that employed academically trained physicists and mathematicians. This is not only true for Germany but also for the other industrialized countries before the Second World War.

Thesis 3

It was common for female industrial researchers to maintain close relationships between industrial laboratories and academic research institutions.

We would like to underscore the following six issues:

(1) Doctoral candidates were able to work on their theses at non-university laboratories, be it at private or industrial facilities. Chapter 1, for instance, is concerned with women who received doctoral degrees in physics and chemistry at the University of Berlin and yet had conducted their research at private laboratories. Similar examples are discussed in Part II (on the electrical industry), Part III (on the chemical industry), and Part IV (on the optical industry).

8 On August 3, 1913, the *Berliner Illustrierte Zeitung* published a photograph of seven male graduates in engineering together with the female graduate Jovanka Bontschits, who later became a famous architect in Belgrade. For a reproduction of the photograph, see Friederike Lübke, "Fräulein Diplom-Ingenieur," *Die Zeit*, No. 38 (September 12, 2013), p. 74.

9 For an early prosopographical study of American mathematicians, physicists, and chemists, see KEVLES (1979). The latter work, however, was not concerned with drawing comparisons based on gender.

(2) Female scientists were able to make career changes from academic institutions to industrial enterprises, and vice versa. This is the main theme of Chapter 1, which describes women scientists in Germany who, between 1912 and 1945, were able to conduct research at some of the institutes of the Kaiser Wilhelm Society as well as in industrial laboratories.

(3) Women working at academic institutions occasionally did so as outside contractors for industrial firms, as was the case with the physicist Hedwig Kohn and her work at the University of Breslau for the OSRAM firm in Berlin. In Chapter 2, Brenda Winnewisser explains that these connections were not only characterized by cooperation but also by competition. Without the expectation of producing specialized industrial research, women scientists could also hold university positions that were nevertheless funded by industrial corporations. For example, the assistant position at the Institute for Applied Mathematics of the University of Jena, which was given to Dorothea Starke, was financed by the famous Carl-Zeiss Foundation from 1928 to 1931 (see Chapter 10).

(4) On occasion, corporations were interested in paying academic female researchers for the right to use their patents, as happened to the physicist Isolde Hausser (see Chapter 5). Other arrangements were made when a company was interested in applying new research findings. A noteworthy example is that of Margarethe von Wrangell, a chemist who made breakthroughs while working in the cities of Reval (today Tallinn, Estonia) and Hohenheim near Stuttgart (Germany). After the First World War, her research caught the attention of the German agricultural and chemical industries – not to mention government offices – and thus in 1923 she was promoted to full professor and made the chair of her own academic institute. Von Wrangell was the first women ever to hold such a position (*ordentliche Professorin*) in Germany, which was housed at the Agricultural University in Hohenheim, and in this capacity she advised the chemical industry on the use of phosphoric acid fertilizers and used its financial resources to conduct agricultural experiments.[10] Waltraud Voss has recently cited another example of newly developed instruments being used in industrial manufacturing processes. The physicist Lieselott Herforth, who was working at an institute of the Academy of Sciences in East Berlin, received a contract with industry because of her success in designing radiation monitoring devices. The contract was arranged between the "Laboratory of Dr. Herforth" and the Carl Zeiss Corporation in Jena, which produced the apparatus after the Second World War. Later, as a full professor at the Technical University of Dresden, Herforth signed contracts with other

10 As early as 1921, Margarethe von Wrangell wrote to her mother: "I am now able to earn as much as I need, but I don't want to take any more than is necessary, even though the industry has given me this opportunity. For, in the end, I want to preserve my freedom as a scientist. […] I was recently in Ludwigshafen again, and I was able to observe the respect that I enjoy there. Above all, this is probably because I have not taken a penny for myself from this billion-Mark company." (quoted in ANDRONIKOW 1936, p. 271). The company in question was BASF. Von Wrangel's institute also received financial support from the Japanese industrial firm Hoshi (see ibid., p. 276). – The Agricultural University in Hohenheim (*Landwirtschaftliche Hochschule*) is now part of the University of Stuttgart.

firms as well, for instance with Vakutronik in Dresden to produce a thermo-luminescence dosimeter, and with the Otto Schön Corporation in Dresden to produce new measurement technology for the field of nuclear physics.[11]

(5) A long-standing career in industry could lead to a permanent university position. In Germany, at least, such transitions were often determined by political change and for political reasons. To name a few, the following women scientists were appointed professors after working successfully as industrial researchers in Germany and the United States: Edith Clarke, Cäcilie Fröhlich (Cecilie Froehlich), Lieselotte Moenke-Blankenburg, Ruth Moufang, Ruth Proksch, Mina Rees, and Iris Runge.[12]

(6) It was also possible to move in the opposite direction, namely from a long-standing academic position to an industrial laboratory. Furthermore, the example of Ingeborg Ginzel indicates that women, like men, conducted war-related research without any scruples. After earning her doctorate at the Technical College of Dresden, Ginzel worked at the Aerodynamics Laboratory (*Aerodynamische Versuchsanstalt*) in Göttingen until the end of the Second World War. After the Nazi defeat, she – like many male aviation specialists – had to write reports about her research for the Allied Forces, in her case for the British Army occupying Göttingen. She left Germany at the onset of the Cold War, first to work in Great Britain and then in the United States, where she became a senior researcher at the Flight Vehicles Research Department of the Glenn L. Martin Company in Baltimore. This was a classified department in which she was the only woman design specialist among forty men. Ginzel published important articles and was honored for her expertise in rocket design. It was this department, incidentally, that was responsible for producing the bombers that would ultimately drop nuclear bombs on Hiroshima and Nagasaki.[13]

11 Waltraud Voss, a mathematician and historian of mathematics, lectured on this subject at the annual conference of the Society of German Mathematicians (*Deutsche Mathematiker-Vereinigung*), which took place in Jena in May of 2013. The contribution will soon be available in print (VOSS 2014, forthcoming).

12 Each of these women scientists and their career paths will be discussed at various points throughout the book.

13 See DOBBIN 1958; Ingeborg Ginzel, *Theorie des räumlichen Tragflügels* (Göttingen: Aerodynamische Versuchsanstalt, 1946); idem, *Die Luftschraube am Stand* (Göttingen: Aerodynamische Versuchsanstalt, 1946); Ingeborg Ginzel and Hans Multhopp, "Wings with Minimum Drag Due to Lift in Supersonic Flow," *Journal of the Aerospace Sciences* 27 (1960), pp. 13–20; Ingeborg Ginzel, "Two Remarks on Cones at Angle of Attack in High Supersonic Flow," *Journal of the Aerospace Sciences* 29 (1962), pp. 497–98; idem, "Bodies of Revolution at Angle of Attack in High Supersonic Flow," *AIAA Journal* 1 (1963), pp. 484–85. As recently as 2013, researchers from the Martin company paid tribute to the German aviation experts who had been working there since the early 1950s (see http://lockheedmartinshare.blogspot.de/2013_04_01_archive.html).

Thesis 4

Aside from the chemical industry, which hired academically trained experts – male and female – somewhat earlier on, other industries generally did not begin to hire women experts until immediately before and during the First World War. At this time, there was a greater need for scientists because many male scientists were conscripted and because industrial technology had become increasingly important to the war effort. It can be said in general that the positions of women researchers were highly dependent on the prevailing social conditions.

Jeffrey Johnson has noted elsewhere that, before the First World War, a campaign had been introduced to prevent women from working in the chemical industry.[14] During that war and in the 1920s, however, women scientists were needed in the laboratories of chemical and pharmaceutical companies. At the time, of course, there were only a few women who were qualified to contribute to such fields and who became acknowledged for their work. An interesting example is Margarete Raunert, who was employed by a pharmaceutical firm in Leipzig, where she had already directed a chemical department even before earning her doctoral degree in 1929 at the University of Jena. She had studied chemistry at the University of Leipzig and worked as an assistant for the famous professor Max Le Blanc from 1916 to 1920.[15]

In Chapter 8, Maria Rentetzi, who has elsewhere investigated the role of women in the radium industry,[16] underscores the marginal role of female scientists at American chemical corporations. Some of them were needed during times of war, after which they were forced to leave their positions. Even the newly established cosmetics industry was largely directed by men. Rentetzi demonstrates that a hallmark of certain outstanding female researchers was their ability to adapt flexibly and quickly to new opportunities.

The role of wars and military research cannot be overestimated.[17] It can be said that women scientists "benefitted" from the wars in question, at least to the extent that such events provided hitherto unavailable career opportunities. Examining women scientists in several branches of industry, we found that they happened to be welcomed more quickly by the corporations founded around the First World War than by older and more established industrial enterprises. Even during the Great War, a number of women researchers, such as Ellen Lax and Isolde Ganswindt (later Hausser), became directors of their own industrial research teams.

14 See JOHNSON 1998.

15 See BISCHOF 2013, pp. xxxiv, 39. On Raunert's later career, see also JOHNSON 1998, p. 81, which is informed by an interview with Raunert conducted in 1989.

16 See RENTETZI 2004, 2008.

17 For general discussions, see TOBIES 2008, pp. 55– 60; VOGT 2000a, 2007, pp. 108–09, 124–25; OLDENZIEL et al. 2000.

Before the Nazi era, science and technology were developing rapidly in Germany, perhaps more so than anywhere else. Many students from abroad were trained and educated at German universities, and foreign researchers travelled to Germany to visit scientific institutions, in part to conduct post-doctoral research. Most of these students and researchers were men, but a number of women also participated in these activities. With the rise of the Nazi regime, however, many female industrial researchers – not to mention many of their male colleagues – were forced to leave Germany and seek positions as elsewhere (see especially Chapter 2 and 6).

During the Second World War, female scientific directors could be found at Telefunken's laboratories in Berlin. Among these were Ilse Müller, who managed a chemical laboratory, and Hildegard Warrentrup, the director of a physical laboratory.[18] During this same time, an example of a woman expert in the German steel industry was the mathematician Ruth Moufang. She had completed her doctorate and her *Habilitation* thesis at the University of Frankfurt am Main, but she could not achieve a paid position as a docent on account of the Nazi policy against women academics. In 1937, she subsequently took a position at the Iron Research Institute in Essen, which belonged to the Krupp steel corporation. After working there for some time, she became a department director in 1942.[19] It was only after 1945 that she was able to secure a teaching position at her alma mater. Similarly, at aviation corporations and in the computer industry, women were granted access to high-level positions during the Second World War because of the absence of men. Melitta Schiller-Stauffenberg, for instance, led her own experimental laboratory for special aircrafts (*Versuchsstelle für Flugsondergeräte*) as late as May 1, 1944.[20]

Ruth Oldenziel and Karin Zachmann were among the first scholars to approach the history of technology from the perspective of gender studies, and the scope of their investigations extended into the Cold War period.[21] This same period is at the heart of Chapter 9 of the present book; in particular, it addresses the contributions of women to nuclear research in the Soviet Union and the United States. The author of the chapter, Peter Bussemer, also examined the work of

18 On the women scientists mentioned here, see Chapter 5; on Ilsolde Ganswindt-Hausser, see also Chapter 1.

19 See RADTKE 2005; PIEPER-SEIER 2008. In her autobiography, Hel Braun described the fate of Ruth Moufang during the Nazi era (see BRAUN 1990).

20 On Melitta Schiller, see BRACKE 2005. OECHTERING 2001 discusses women in computer science. On women scientists who were active in military research, see VOGT 2000a, 2007, pp. 258–60, 326–33.

21 See OLDENZIEL/ZACHMANN 1999, 2000, and 2009. On the special case of the mobilization of women engineers in East Germany, see ZACHMANN 2004. In 2013, the annual meeting of the German Society for the History of Medicine, Science, and Technology [*Deutsche Gesellschaft für Geschichte der Medizin, Naturwissemschaft und Technik*] took place in Jena and was devoted to the theme of "Science during the Cold War," and we benefited considerably from the discussions that took place. The research of one of the keynote speakers, Alexei Kojevnikov, is closely related to the studies presented in this book (see especially KOJEVNIKOV 2004).

German "specialists" employed in the Soviet Union after 1945, and was thus able uncover remarkable links between Russian and German research. In Chapter 11, Bussemer has examined the interactions between Russian and German developments in the field of applied optics, especially during the time just before and after the Second World War. Two additional chapters are concerned with the Cold War years, both of which provide an analysis of the working conditions for women that prevailed at the Carl Zeiss Corporation in East Germany (see Chapters 12 and 13).

Thesis 5

Patronage relationships were not only crucial for women specialists to reach higher positions at industrial laboratories; they also played a significant role in many other aspects of their careers.

At the time, during which only a few female scientists were able to secure positions in industrial laboratories, patrons exercised considerable influence over women's careers. Patronage, incidentally, is a rather newly explored field in the history of science.[22] At the 24th International Congress of History of Science, Technology, and Medicine a special symposium titled "Mathematics and Patronage" was organized by June Barrow-Green and Reinhard Siegmund-Schultze.[23] The participants discussed patronage relationships as they existed in several countries, at different periods, and in different contexts.

An influential patron to a female engineer in the United States, for example, was George A. Campbell, and not only because of his international training. Before he became an industrial researcher at the American Telephone and Telegraph Company in Boston in 1897, Campbell had studied in Europe under the mathematician Felix Klein, among others, at the University of Göttingen. Even at that time, Klein was known for his support of women students and of their opportunity to pursue doctoral degrees.[24] Perhaps Campbell had been influenced by this attitude; back in the United States, in any case, he became an important patron to the aforementioned Edith Clarke. Another example of patronage was the relationship between the aforementioned Margarethe von Wrangell (see Thesis 3 above), Germany's first female full professor, and Fritz Haber, a Nobel Prize winner. He held her research in high esteem, wrote positive reviews of her articles, and offered her a position as a guest scholar at his Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry in Berlin. She worked there from 1922 to 1923, and

22 For a general explanation of patronage, see SIMPSON (1988). On the role of patronage in science during the nineteenth century, see TURNER 1976.

23 See also SIEGMUND-SCHULTZE 2001, 2009.

24 In 1895, the American mathematician Mary Frances Winston and the English mathematician Grace Chisholm completed their doctoral degrees under Klein's direction at the University of Göttingen (see TOBIES 1999).

Haber finally arranged for Margarethe von Wrangell to become a full professor at the Agricultural University in Hohenheim.[25]

Chapter 5 of this book presents some findings concerning the promotion of women scientists by patrons in the electrical industry. These patrons were directors of industrial research departments who were renowned scientists, engineers, and inventors. They were shrewd enough to evaluate with accuracy the scientific capabilities of women and men alike, though it remains unclear to what extent the gender of scientists might have affected the objectivity of their judgements.[26] Chapter 6 describes the eminent career of the German-American applied mathematician Cäcilie Fröhlich, a career in electrical engineering that would have been inconceivable without the patronage of a few important research directors.

Thesis 6

The working conditions for women scientists varied across different sectors of industry; at their most favorable, such scientists were encouraged to produce important research findings and even to apply for patents.

The topic of female inventors, especially in Great Britain and the United States, has been treated in some detail by Ethlie Ann Vare and Greg Ptacek (see their books published in 1988, 1993, and 2002). In Chapter 1, Annette Vogt considers the history of patents for invention from the perspective of female patentees who had worked for some time at one of the institutes of the Kaiser Wilhelm Society in Germany. In Chapter 2, Brenda Winnewisser emphasizes the role of Hedwig Kohn's patent for arc lamps filled with several inert gases, which she developed together with a female doctoral student. Chapter 5, moreover, offers a survey of female researchers in electrical corporations who earned patents in Germany, Great Britain, the United States, and Canada. These patents were occasionally earned together with male colleagues and research directors.

Whereas Jeffrey Johnson has stressed that, in the chemical industry, most women chemists were busy with so-called "women's work" – that is, with administrative or library jobs – we discovered several female researchers at different electrical and communications firms who, as early as the 1920s, were able to acquire patents for their inventions. Patents can tell a great deal about the scientific contributions of female researchers; in general, patent applications serve as an informative primary source for historical investigations.

25 See ANDRONIKOW(-WRANGELL) 1930; ANDRONIKOW 1936, pp. 242, 272, 274; VOGT 2007, pp. 138, 140, 174; VOGT 2008, p. 217–18, and OFFEREINS 2011.

26 On the notion of objectivity, see DASTON 1997, 1998; DASTON/GALISON 2007.

Thesis 7

No particular field of industrial research can be labelled "feminine," though women scientists with interdisciplinary training did contribute to the introduction of new sectors of industry.

The title of Londa Schiebinger's book *Frauen forschen anders* can be translated as "women conduct research differently" (the English version of the book is entitled *Has Feminism Changed Science?*). It is appropriate to wonder whether this is truly the case and, if so, why? While it is true that many women were relegated to "assistant positions" (*Hilfestellungen*), in which they had to perform routine tasks, [27] it must also be admitted that there were also men who occupied such positions, and that jobs of this sort allowed a number of women to advance their careers.

The cosmetics industry, for example, which was established during the 1930s in the United States and Europe, would seem at first glance to be a principally "female" sector of business. However, Maria Rentetzki investigated the role of women in this industry and offered the following blunt conclusion: "Cosmetic Chemistry: A Field Closed to Women" (see Chapter 8). Although there were a few successful female researchers who contributed to the elevation of cosmetology into a scientific discipline – a highly interdisciplinary process – most of the leading positions were occupied by men.

The application of mathematical methods to the problems faced in industrial laboratories likewise required interdisciplinary training. A new style of thinking, captured in the motto "calculation instead of trial and error," became an important element of industrial research. We were able to identify calculation departments in the optical and electrical industries as early as the year 1900, but they were all led by men. However, in the newly founded corporations in the communications, aviation, and computer industries, increasingly more mathematically educated women were hired to work alongside male colleagues. On some occasions it happened that only one female researcher determined this new style of thinking within a specific industrial company.

Edith Clarke, who has been mentioned above, was known as a "human computer" at the American Telephone and Telegraph Company (later AT&T), which she joined in 1912. She made calculations for George Campbell, her professional mentor, who applied mathematical methods to the problems of long-distance electrical transmissions. When, in 1925, Western Electric and part of AT&T formed the Bell Telephone Laboratories, the use of mathematical methods and the participation of women researchers increased. Thornton Fry, who held a doctoral degree in mathematics, established the first mathematical research department in the Bell Telephone Laboratories in 1928. Later he explained: "The practical engineer got his mathematics where he could – often through self-education, sometimes by seeking the help of his long-haired colleagues."[28] Claude Shannon,

27 See BRÜGGENTHIES/DICK 2005; OECHTERING 2001.
28 FRY 1964, p. 936.

known as the father of information theory, was for some time a member of Fry's research department, and there he met his wife, the numerical analyst Elizabeth (Betty) Moore. During the Second World War, relatively many female mathematicians were involved in war research programs. Some of them, like Mina Rees, [29] began their careers in naval research, and others in the field of computer science. An extraordinary woman in the latter field was Grace Hopper, who was not only famous for inventing the first compiler but also worked as a mathematical consultant for several computer corporations.[30] Regarding women working in the computer industry, however, it has been rightfully noted that they had the opportunity to participate at the forefront of a new science, but were later elbowed out.[31]

During the first decades of the twentieth century, most industrial companies employed only a few individuals as mathematical consultants, as Thornton Fry once pointed out regarding industry in America.[32] In Germany, Iris Runge, who was the eldest daughter of the mathematician Carl Runge, worked as such a consultant at the OSRAM Corporation from 1923 to 1939, and at Telefunken from 1939 to 1945. It was she who introduced the catchphrase "calculation instead of trial and error" at OSRAM's laboratories, and she brought this philosophy with her to Telefunken as well.[33] Cäcilie Fröhlich was another woman with an outstanding command of mathematics. She was employed by AEG, a German electrical company in Berlin, from 1928 to 1937, at which point she had to leave Germany on account of Nazi policies. Ruth Moufang's position as the head of a department at the Krupp Iron Institute was also possible thanks to her mathematical acumen.[34]

Toward the end of the 1920s, when positions at secondary schools were restricted because of the world economic crisis, trained mathematicians sought positions in other fields, especially at the newly founded research institutes associated with the aviation industry. We have identified at least six women mathematicians who made noteworthy contributions to German aviation research, much of which was conducted for the military:

(1) Dora Wehage, for example, became qualified to teach mathematics, physics, and philosophy in 1920.[35] As of 1925, she worked as a mathematician at the Weapons Agency of the German Army (*Heereswaffenamt*), and soon thereafter, in

29 On Mina Rees, see BROOME WILLIAMS 2001, 2003; SHELL-GELLASCH 2002, 2011. When Rees died in October of 1997, *The New York Times* published an obituary written by Wolfgang Saxon. See also her obituary in *Notices of the AMS* 45 (1998), pp. 866–73.

30 See OECHTERING 2001; BROOME WILLIAMS 2001.

31 See TOBIES 2008, pp. 63–66.

32 See FRY 1964.

33 See TOBIES 2013.

34 Moufang's academic contributions to mathematics include the following articles: Ruth Moufang, "Das plastische Verhalten von dünnwandigen Rohren unter statischem Innendruck," *Zeitschrift für angewandte Mathematik und Mechanik* 20 (1940), pp. 24–37; and idem, "Das plastische Verhalten von Rohren unter statischem Innendruck bei verschwindender Längsdehnung im Bereich endlicher Verformungen," *Ingenieur-Archiv* 12 (1941), pp. 265–83. See also PIEPER-SEIER 2008, p. 199.

35 See [BBF] Karteikarte.

1928, she completed her doctorate at the Technical University of Berlin (her thesis concerned the numerical mathematics of partial differential equations). Later, Wehage became a leading mathematician in Peenemünde, a village on the island of Usedom in the Baltic Sea where the V 2 was developed.

(2) Irmgard Lotz (later Flügge-Lotz) received her doctoral degree in applied mathematics at the Technical University of Hanover in 1929. She then became an assistant at the Kaiser Wilhelm Institute for Fluid Mechanics, where she conducted aviation research based heavily on mathematics.

(3) Ingeborg Ginzel, who was mentioned above, became a colleague of Irmgard Flügge-Lotz on the strength of her doctoral dissertation, which she completed in 1930 at the Technical University of Dresden in the field of conformal mapping.

(4) Marie-Luise Schluckebier, who defended her dissertation in 1935 at the University of Bonn, was one of the last doctoral students of the mathematician Otto Toeplitz, who was able to emigrate and escape the Nazi persecution. She found a job in aviation research, and after the war she received a position at a branch of AEG in Kassel.

(5) Melitta Schiller (later Stauffenberg) earned a *Diplom* in engineering from the Technical University of Munich, where she also passed a special examination in higher mathematics. Although she was "half Jewish" according to Nazi terminology, she found a position in aviation research as a test pilot, and she cooperated with several aircraft firms in Germany until the end of the Nazi regime in 1945.

(6) Ruth Proksch passed examinations to become a secondary school teacher in mathematics, physics, and chemistry, after which she worked as a mathematician for Fieseler Flugzeugwerke, an aircraft manufacturer in Kassel, without having a doctoral degree. To carry out industrial research, she ultimately completed her doctorate at the Technical University of Breslau (today Wrocław in Poland) in 1943.[36]

Previous investigations have shown that social pressure was a more influential factor than gender in determining a scientist's workplace and area of research. That said, it could also be possible that women, as relative "outsiders" in scientific disciplines, were less reliant on traditional theories and were more willing to apply innovative research methods.[37] It is merely a hypothetical question whether science has developed as it has because it was essentially shaped by men and whether women, if only they had had the means and authority, would have produced a *different* type of science with *different* theories. We are thus in agreement with Londa Schiebinger, who, in an interview from 2001, qualified her deliber-

36 TOBIES 2008, pp. 115–118. On Flügge-Lotz and Ginzel, see also Chapter 1 of this book. Short biographies of these mathematicians are included in TOBIES 2006, which is available online at https://dmv.mathematik.de/m-die-dmv/m-geschichte.html. For additional information about Flügge-Lotz, see SPREITER 1975; SPREITER/FLÜGGE 1987; VOGT 2000a, pp. 199–204.

37 See ABIR-AM/OUTRAM 1989.

ately provocative thesis – "women conduct research differently" – in the following terms:

> In fact, I do not at all believe that women conduct research in a different way. [...] Even the search for a specifically feminine type of knowledge is, in my opinion, a dead end. [...] We have to abandon the idea that women – as a gender – change science. [...] As a biological category, "women" often have no interest whatsoever in altering gender roles. Moreover, those men who are interested in overcoming the gendered divide between "intellectual" and "emotional" types of work in our society are our closest allies.[38]

Thesis 8

The increasing acknowledgement and acceptance of female inventors and female industrial researchers can be shown by studying their membership in scientific organizations, societies, and associations.

The membership of women scientists in scientific societies and associations is discussed in this book as an aspect of patronage, especially in the case of membership in physical societies (see Chapter 5). The first female researchers who were members of electrical engineering institutions are also mentioned (see the Introduction to Part II). At the same time, some professional and academic societies were established exclusively by and for women scientists; Jeffrey Johnson discusses such societies devoted to chemistry in Chapter 7. Reinhard E. Schielecke has recently noted that fifteen women had joined the internationally influential Astronomical Society, which was founded in 1863 in Heidelberg, before the year 1930. Four of these female members came from the United States (among them the famous Margaret Harwood), three from Soviet Union and Germany, and one each from Denmark, France, Hungary, Sweden, and Great Britain. Four additional German women joined before 1945, two in 1935 (among them Dorothea Werner-Starke, who was closely affiliated with the Carl Zeiss Corporation), one in 1937, and one in 1940.[39] Ilse Ter Meer, who will be mentioned again below, became the first female member of the Association of German Engineers (*Verein Deutscher Ingenieure*), which was established in 1856.

Regarding scientific societies in Germany, women scientists were accepted earlier on by societies in the fields of mathematics, science, and engineering than they were by societies concerned with economics, history, and disciplines in the humanities. The matter worsens when we look at the most prestigious scientific organization of them all – the Academy of Sciences. With a few extraordinary exceptions, none of the Academies of Sciences in Europe and the United States elected female members before 1945. There were various reasons for this frustrating situation, and these differed from one Academy to the next. However, the argumentation against admitting female members to these organizations, which

38 SCHIEBINGER 2001, p. 30.
39 See SCHIELICKE 2013.