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2012

https://doi.org/10.25595/147

Veröffentlichungsversion / published version

Zeitschriftenartikel / journal article

Gender & History ISSN 0953-5233
Helga Satzinger, 'The Politics of Gender Concepts in Genetics and Hormone Research in Germany, 1900–1940'
Gender & History, Vol.24 No.3 November 2012, pp. 735–754.

The Politics of Gender Concepts in Genetics and Hormone Research in Germany, 1900–1940

Helga Satzinger

The history of biological understandings of sex difference and sex determination reveals a surprising variety of conflicting views. In the first half of the twentieth century, notions of a binary and discontinuous sex difference competed with more fluid concepts of a binary order postulating the two poles of male and female connected by a continuum of different stages of 'intersexuality'. Genetic experiments laid the groundwork for new claims that male or female organisms resulted from the combined effects of male and female genetic factors with possible intermediate stages of 'intersexes'. Following a contrasting model in biochemistry, sex hormones were framed in a binary male-female order despite contradictory experimental results. The results of genetics and hormone research, moreover, entered into different political debates and struggles around gender. Around 1900, for example, the supporters of gender equality used the brand new theory of chromosomes' crucial role in inheritance to argue for women's university education. In the 1920s and 1930s genetic concepts of sex determination showed up in the conflicting debates about homosexuality, blurring gender norms, degeneration, racial purity and miscegenation.

The history of these and other conflicting concepts reveals how deeply scientific concepts were informed by political aims and desired or abhorred gender orders. These concepts were never based on purely 'scientific' or experimental results alone. It is not unusual for historians of science to find this sort of influence, as the construction of knowledge is understood as a process of social negotiation in interaction with the 'Eigensinn' (intrinsic logic) of the investigated objects, theories and experimental systems used; it is deeply embedded in historical contingencies.[1]

My account of the politics of gender concepts in the history of genetics and hormone research in Germany between 1900 and 1940 revises existing histories of biological sex determination based on sources in the English language from the second half of the twentieth century. These histories follow a narrative of a binary, masculinist concept of sex determination in the 1950s, evolving into a more balanced concept by the 1990s, a concept which finally transcends the binary. The evolution is seen as being brought about by feminist and queer interventions.[2] Going back to earlier decades of the century and to a different scientific arena, however, reveals a more nuanced and contradictory historical process. There is no simple story of linear progress to tell, and the story does not begin with a strictly binary, 'two-sex-model' of difference.[3]

By unravelling the politics of multiple gender concepts in the sciences of the early twentieth century I hope to link the history of the scientific study of sex difference with gender historians' work on multiplicities of genders and their continuous renegotiation.[4] Social history has shown convincingly how various gender orders have been invented, explored and contested. So it should not surprise us that in the sciences as well, there was not one and only one gender order at stake. As a historian of science I investigate scientific concepts of sex difference as resulting from various social – and gendered – processes, in which authority, power, responsibility and relevance are attributed to scientists, scientific concepts and practices, to the choice of objects and explanatory models. Taking my cue from gender history, whereby the meaning of female and male is very malleable, I investigate the gendering of scientific objects or concepts – such as sex difference, hormones, genes, chromosomes and germ cells. I examine how these epistemic objects were shaped by and embodied political debates about the gender order and how they, in turn, influenced them.

Sex/gender, nature/culture and Mother Nature's 'political correctness'

Let me first clarify two points related to the terms 'sex' and 'gender', to prevent possible misunderstanding. The use of the term gender is problematic, especially when talking about biological understandings of sex difference.[5] The German language has one term for sex and gender, "Geschlecht", which does not distinguish between the "natural" and the "cultural". The English distinction between sex and gender, on the other hand, often sets up a 'natural' or biological entity – 'sex'– and leaves its investigation to the sciences.[6] However, feminist science studies showed that there was no gender-free concept of biological 'sex difference' even before Judith Butler pointed out the conceptual flaws of the sex-gender distinction.[7] Writing in English on biological concepts of 'sex difference' creates the problem of how to find a new term for 'sex' to indicate that biologists also 'do gender' when investigating 'sex difference'. With no alternative at hand I will still use the terms 'sex', 'sex difference' and 'sex determination' when I refer to scientists' efforts to deal with what they see as the nature of the difference between humans of different generative potential. I also want to stress the point that we have no adequate terminology yet to describe and account for the materiality of different bodies while avoiding the gendered assumptions of the biological sciences. Even the biological constituents of the body, like 'cells', 'genes', 'hormones' and 'chromosomes' embody gendered concepts, which I hope to show.

The nature/culture and sex/gender conceptual divides create another problem. During the last few decades feminist science studies have shown convincingly how social concepts of gender shape scientific knowledge. Biology is a particularly striking and obvious example as some of its topics deal with sex difference and sex determination, procreation, male or female behaviour and heredity, to name a few areas where gender is an inevitable part of the process of knowledge production and knowledge itself. Biology and medical sciences of the nineteenth and twentieth centuries were crucial tools in the construction of knowledge about women's nature and the legitimation of their subordination.[8] It was, and is, a very important task to deconstruct biological and medical concepts of gender which reiterate all too familiar sexist claims about women's difference from men, be it mathematical ability, orientation in space or reproductive strategies. Based on the critical deconstruction of those gender concepts, several authors in science and gender studies claim that 'better science' would be possible once gender biases were removed. Once feminist perspectives prevail and pose new questions, the argument goes, neglected topics could come to the fore, thus restructuring and innovating knowledge for the better.[9]

However, there is a blind spot in this argument. It is based on a tacit and a very old assumption, already used by women like Mary Wollstonecraft and Olympe de Gouges in the late-eighteenth century: nature does not know a hierarchical gender order.[10] Today we still find the assumption lurking in feminist critiques that once we investigate 'nature' in a gender-neutral way, we will find nature's undistorted and 'true' properties. The natural world is posited as 'politically correct', waiting to be discovered. Historians of science are usually more sceptical with regards to 'scientific facts' of the natural world. For them, the investigative processes by which scientific facts are 'fabricated' are the focus of attention. It is not really important, or at least it should not be important, if those facts themselves meet the expectations of the historian. But, is it really no problem, when 'nature' defies the feminist investigators' political convictions with regard to the appropriate gender order? Usually the discovery of 'gender stereotypes' in scientific concepts – whatever they might be – rings alarm bells, indicating that something might be wrong with these scientific facts. But the opposite case seems to go unnoticed. There is no alarm bell ringing when the scientific fact meets a contemporary feminist norm of gender difference.

Three examples taken from the recent history of biology illustrate that the presumption of a 'politically incorrect nature' is rather unusual in feminist science studies. Scott Gilbert and Karen Rader investigated the substantial participation of women scientists in developmental genetics in the second half of the twentieth century. They concluded that the prominent presence of women in this scientific discipline helped to overcome masculinist assumptions and to come to a better, or more adequate, understanding of embryonic development.[11] In a similar line of thought Sarah Richardson argued that the influence of an outspoken feminist scientist led to investigating the process of sex determination in humans in a new and more appropriate way in the 1990s.[12] This scientific intervention was successful at this particular point in time as the general social atmosphere encouraged the exploration of new gender concepts. According to Richardson, the prevalent focus on male development and the neglect of female development, as well as the belief in the normality of a strict binary order was thus overcome by the end of the 1990s. Finally, in her 1996 paper 'Gender and Genitals', Ruth Hubbard criticised the '[w]estern assumption that there are only two sexes', which 'probably derives from our culture's close linkage between sex and procreation'. In her view, 'this binary concept does not reflect biological reality'.[13] To illustrate this, she referred to various forms of 'intersexes' and societies where these 'intersexes' were regarded as normal human variants. In the Dominican Republic, for example, some girls usually developed into young men during puberty. This transformation was seen as normal by the villagers, whereas western scientists explained it as an effect of a specific and pathological testosterone metabolism in individuals with a 'male' x-y chromosome status, preventing male development before puberty. In conclusion Hubbard asked the medical profession 'to remove their binary spectacles and, rather than explore what it means to be "male" or "female", look into what it means to be neither or both, which is what most of us are'.[14] In Hubbard's approach sex and gender blur; people with all sorts of bodies assign themselves a particular social identity, which is no longer framed in a binary sex/gender system. By doing so, she argued, these people question their pathologisation of sexual indeterminacy by the medical and biological professions. Hubbard's example shows two ways of referring to 'nature'. On the one hand, there are people using the notion of pathology to posit a seemingly natural order in which there are men and women only, with their clear-cut difference defined by their reproductive potential. Variations are pathologies that demand medical intervention. On the other hand, there are people or cultures, including even some scientists, which create and provide social spaces for all individuals who are there, 'naturally', by birth, without superimposing a binary gender order.[15] The ethical foundation of Hubbard's approach follows the conviction that everyone born has the right to exist, and medicine and science should not help to create social discrimination.[16] According to Hubbard nature offers more than two sexes, therefore medicine and the biological sciences should not impose a binary sex/gender order.

But, why should we refer to 'nature' to legitimate anti-discriminatory politics? Can we assume that 'nature' is politically correct and prepared to help us against discrimination? Is it just a matter of getting the sciences on the right political track and then we will discover or 'reinvent' 'nature' as it is out there, happily, perfectly compatible with our political convictions? Even if this were the case, I would argue that we should not base our politics on the sciences.

'Primatology is politics by other means', Donna Haraway claimed provocatively some years ago.[17] Primatology is a contested scientific arena, where concepts of human 'nature' and sex difference are developed. Haraway showed convincingly how the successive intervention of female and feminist anthropologists changed the gendered agenda and concepts of primatology and that they conceptualised more than one gender order. But Haraway also showed that this feminist intervention remained within the conceptual paradigm of sociobiology, and therefore, within the understanding that our nature and 'reproductive strategies' simply reflect investment strategies in a competitive, capitalist society. In a similar line of thought I wish to show how genetics and endocrinology, in dealing with concepts of sex difference and sex determination, developed not one but different gender orders which, in a highly contradictory way, were part of the politics of their times. To support the claim that scientific concepts are politics by other means, I will investigate what exactly was on the political agenda.

Gender politics in the sciences

I identify three arenas for examining the politics of gender concepts at work in genetics and hormone research: the creation of scientific knowledge and its consequences for the dynamics of the respective science, the use of scientific gender concepts in political debates and the gendered organisation of scientific work, where women and men had different tasks, duties and authority.[18] In those three arenas of science, gender orders were invented and negotiated, although we cannot assume a direct causality between the gender order of the workplace, the knowledge produced and the politics supported. The social gender orders did not translate directly into the scientific ones, and vice versa. There was always tension, contradiction and asynchronicity. There were also specific disciplinary traditions, experimental systems and concepts, which incorporated and perpetuated certain gender concepts. These concepts could not be overcome just by changing the social gender order – at least in the short time frame of my study. Moreover, a gender concept could act as liberating in one arena, while stabilising a hierarchical order in another. This will be shown in more detail below.

My case studies come from zoological genetics and biochemical hormone research in Germany, and in particular, from the work of two zoologists and one biochemist and their male and female co-workers.[19] Theodor Boveri (1862–1915), Richard Goldschmidt (1878–1958) and Adolf Butenandt (1903–1990) were all key figures in their scientific fields. Boveri is known even today for his identification of chromosomes as the sites of the inheritable units we now call genes. Goldschmidt was a leading geneticist in the 1920s in Germany, who was both inspirational and controversial. Butenandt became famous for the chemical isolation of 'sex-hormones' from the late 1920s onwards. The three eventually reached the highest possible scientific positions in Germany. Boveri acted in 1913 and 1914 as founding director of the Kaiser Wilhelm Institute (KWI) for Biology; Goldschmidt became head of one of its departments (1914–1935) and Butenandt became director of the KWI for Biochemistry in 1936, all in Berlin. They worked during times of dramatic political change: from the time of the Empire (Boveri and Goldschmidt), to the Weimar Republic and then National Socialism (Goldschmidt and Butenandt). Goldschmidt, who was Jewish, was forced to emigrate in 1935–36 because of Nazi anti-Semitism, whereas Butenandt was able to advance his career by active collaboration with the Nazi regime. He even stayed at the top after 1945, when he became president of the Max Planck Society, and he remained a leading figure in West German biomedical research until the 1970s.[20] The early decades of the twentieth century also saw the feminist struggle for equality, suffrage and economic independence; the decriminalisation of male homosexuality and, confronting these movements, the anti-democratic and anti-feminist efforts of the völkish and Nazi political movement that succeeded in 1933 with the establishment of a totalitarian regime in Germany.

During these same years dramatic achievements occurred in the biological sciences. With the rediscovery of Gregor Mendel's laws of inheritance in 1900, genetics developed as a new discipline. In 1905 Nettie M. Stevens (1861–1912) and Edmund Wilson (1856–1939) proposed a new concept of sex difference as hereditary. It was no longer believed to be nutrition or special circumstances during conception that decided the sex of the offspring.[21] Now genetic factors were seen as responsible for the development of a fertilised egg cell into a male or female organism; observable chromosomal difference could be correlated to sex difference, suggesting a causal connection. In the 1920s hormone research approached the biological riddle of sex difference by isolating and identifying those gonadal substances that could be seen as responsible for the development of adult males or females.[22]

Things turned out to be rather complicated, and the binary either-or logic of sex difference did not account for all the observations and experimental results. 'Intersexes' became part of the evolving theories of sex difference, which could range from minor, irrelevant variations of the normal state to severe pathologies in need of surgical or pharmaceutical intervention.[23] As will be shown in more detail below, gender difference became in a new way a matter of racial difference in the 1920s and a subject of normative practices aimed against Jewish assimilation and Jewish-German marriages. Race and gender were not only analogous in their classifying powers, but also conceptually interwoven. When sex hormones were first investigated, they were classified as male or female, but soon they transcended the scientists' attempts to order them. Female hormones were found in male organisms; male hormones could have feminising effects in experimental settings. Thus, they became 'heterosexual' hormones.[24] The hormonal gender trouble was severe, and the Dutch biochemist John Freud proposed in 1936 to abandon the classification of sex hormones completely and use the name 'growth promoters' instead.[25] However, despite this observed gender unruliness, there is no convincing historiographic explanation of why the concept of male and female sex hormones, with gender inscribed into their very names like oestrogen or prostaglandin, has survived the twentieth century.

Gender at the workplace

Before going into more detail about these scientific developments, I will identify elements of the gender order in the scientific workplace of the three research groups around Boveri, Goldschmidt and Butenandt. All three cases belong to a time when the model of the male breadwinner in heterosexual married couples was normative. Earning their own living was acceptable for women only before marriage or in other exceptional cases. In the first decade of the twentieth century, women were formally admitted to university study in Germany, but a professional career in academia was a rare exception for women; even today they have severe difficulties gaining influential positions equalling those of men.[26]

In the decades covered here, women worked in all the research groups under investigation. Their work was of crucial importance; however, the gender order in their workplaces did not grant them equality. Theodor and Marcella Boveri (née O'Grady, 1863–1950) were a binational married couple, both scientists with equivalent educations. Marcella Boveri stayed in her husband's shadow, collaborating on experiments and publishing only one paper on her own. Marcella came from the US where she had teaching and research positions at Bryn Mawr and Vassar College. She had come to the University of Würzburg to study for her Ph.D. with Theodor Boveri but married him instead. She was the first woman to be admitted to Würzburg to study. The authorities could not reject her as she had previous scientific training.

As Theodore Boveri's wife, she was of importance not only as his collaborator but also as a pioneering woman scientist, helping to open the university doors to German women. Her success was a paradoxical one. She demonstrated that women who had studied at universities did not necessarily compete with men on the job market but potentially improved the career chances of their husbands if they worked in the same field. The Boveris became important mentors and supporters of women's university education; they mentored nearly half of all women who earned a Ph.D. at Würzburg before 1914. In addition, Boveri's institute hosted several women scientists from the US as visiting scholars, providing research opportunities that furthered their careers at colleges in the US. Some of these women contributed substantially to Theodor Boveri's research by solving methodological problems relevant to his approach. [27]

The case of Richard Goldschmidt was different as he was not a professor at a university. He offered opportunities to postdoctoral women scientists at his KWI department in Berlin where they could pursue research, but only one woman, Mathilde Hertz (1891–1975), got a permanent paid position that lasted until her forced emigration in 1935–36.[28] In his later years in the US, when Goldschmidt was older and less powerful, women became his main collaborators.[29] As one of the very few senior geneticists of the 1940s and 1950s, he appreciated the work of maize geneticist, Barbara McClintock (1902–1992), who, in 1983, was to be awarded the Nobel Prize for Physiology or Medicine for her early work on transposable elements in the chromosomes. This work challenged the leading genetic concepts of her time, but was not well received. Both Goldschmidt and McClintock referred positively and supportively to each other's work in the 1950s, at times when he was highly controversial and she found herself rather isolated in the scientific community.[30] In his Berlin years Goldschmidt had mostly relied on the support of women working in subordinate positions at the institute – librarians, multilingual secretaries and technical assistants.[31]

In the early years of the twentieth century, the 'technical assistant' was established as a new profession for women in the sciences and medicine in Germany. Technical assistants had their own specific formal educational requirements and examinations and worked in clinics, research laboratories, industry and governmental institutions. Scientific work had started to require large-scale data production and processing. A division of labour evolved which made an educated support staff necessary in science laboratories. In this situation the new profession of 'technical assistant' met the needs of scientists and of women who did not want to or were unable to invest a lot of money in academic study. An academic education could not promise women secure job prospects. Working as a technical assistant, however, gave women the opportunity to earn a living before marriage or sustain themselves at a very modest level, if they decided to or had to stay single, and they could work in the sciences without having to compete with men for academic positions. Goldschmidt could draw on the work of those women for his large-scale breeding experiments, for example, for the care of the animals and for the collection and evaluation of the experimental data.

The biochemist Adolf Butenandt also needed the skills of female technical assistants for the large-scale animal testing required for his hormone isolation projects. He started his career and first efforts to isolate the female hormone with his later wife, Erika von Ziegner (1906–1990), and several other women working as technical assistants on the physiological tests. In his laboratories, there was a gendered division of labour between male academic chemists and female technical assistants. For Butenandt women clearly had to restrict themselves to supporting men, and there is ample evidence that he could not tolerate independent women scientists.[32]

In all the cases covered, the gender order at the workplace was characterised by the male head of the household and head of the institute or research group. Usually women worked in a supportive position, either as the academically trained wife, the Ph.D. student or the female technical assistant. Single women academics, in highly precarious positions, collaborated with these groups, mostly for a short time. But, basically, women did not become equals in scientific workplaces. The prevalence of technical assistants even suggests that this new profession in German scientific research helped to keep women out of academic training and to reduce the competition between men and women on the academic job market. Despite these limitations, since around 1900 the gender order had gained a certain flexibility with regard to women's education and employment. During the Weimar Republic there was more openness to women's independence and their pursuit of professional careers – one might even say there was evidence of some sort of early gender bending. This limited experimentation ended in 1933. The model of the male breadwinner in a heterosexual couple remained the dominant model for the time investigated and far beyond.

Chromosomes and gender equality

In the late nineteenth century, until his untimely death in 1915, Theodor Boveri and his wife Marcella investigated hereditary processes at the level of cells, which were regarded as the smallest unit of a living organism.[33] At centre stage was the investigation of the paternal and maternal contribution to the next generation. They investigated which cellular material was transmitted and whether it was transmitted equally from each parent. Consequently, cell division, the creation of germ cells, their fusion in fertilisation and the subsequent development of an organism became the objects of study. In the nineteenth century August Weismann (1834–1914) and Ernst Naegeli (1817–1891) had proposed the hypothesis that there must be a minute substance in every cell which contained the plan for the whole organism, and which was transmitted via cell division to the 'daughter cells'.[34] The problem was identifying the hereditary substances coming from the paternal and maternal organisms. The Boveris used microscopy, staining techniques and carefully designed experiments. Their model organisms were sea urchins and the parasitic worm, Ascaris megalocephala. Both species had, in the eyes of the zoologists, male and female forms and could serve as a model for the human case.

Within the cells certain stainable particles could be identified. They became visible during cell division, were transmitted to the daughter cells but then disappeared until the next cycle of cell division started. These particles – chromosomes – were the perfect candidates to be identified as the heredity-bearing substance, as they are still considered today. But careful investigation and experimentation was necessary to prove that in every cell cycle the same number of chromosomes appeared in the same form and that each of them had its own specific and irreplaceable relevance for the normal development of an organism. In the years 1902–1904, shortly after the rediscovery of the Mendelian laws of inheritance, Theodor Boveri identified the chromosomes as the material entity on which Mendelian 'Anlagen' – later called genes – were situated. He saw the chromosomes as the crucial substance of heredity, which always in pairs, were passed on from one cell generation to the next. One set of the pair came from the maternal organism and one from the paternal organism via their egg cell or spermatozoon, respectively, which had fused during fertilisation. Boveri's interpretation was later called the chromosomal theory of heredity and became one of the building blocks of the science of genetics. Chromosomes are today seen as containing the substance DNA, which carries the genes that, by coding for proteins and their regulation, supposedly determine every organism and its function.

A precondition for the identification of the chromosomes as the hereditary material was a new interpretation of fertilisation as the fusion of two morphologically and functionally different germ cells, the 'female' egg cell and 'male' spermatozoon. In 1902 Theodor Boveri described fertilisation with a special focus on the movements and distribution of chromosomes. He could show that the spermatozoon contributed chromosomes only to the next generation.[35] The chromosomes of the paternal and maternal cells joined in pairs, and Boveri initially believed in the complete equality of the two sets of chromosomes in terms of shape, size and function. It was only some years later that new findings on chromosomal sex determination made him change his mind.

Around 1900 evolutionary thought and the view that cell division was the primordial mode of reproduction created a problem: the existence and function of the male spermatozoon was in need of explanation. Theodor Boveri came to a conclusion, which, curiously enough and in one respect only, resembles a rather recent interpretation of the evolutionary position of the y-chromosome, now usually understood as the chromosome characterising male mammals.[36] According to Boveri, in early evolution the primordial cell was characterised by its ability to divide into two 'daughter'-cells. The next step in evolution was the fusion of two cells forming a new organism. Then, those cells that aggregated into colonies or 'families' of sixteen cells differentiated by size and thus formed primordial germ cells, with the smaller one becoming the prototype, so to speak, of the male and the larger one of the female germ cell. From this evolutionary step onwards, the 'male' spermatozoon was in a process of continuous miniaturisation, until it contained only chromosomes. The chromosomes were the only material necessary for the 'male' role in reproduction; they guaranteed the spermatozoon's and the male's further existence in producing the variability of the next generation. Basically, even until today, the production of variability is seen as the reason why heterosexual reproduction has evolved. Why the primordial 'maternal' cell produced different offspring in the first instance was, however, neither questioned nor explained by Boveri. Evolutionary progress, differentiation and variation of and within species became dependent on the 'invention' of the male and sexual reproduction; with this hypothesis, the spermatozoon (and the male) gained its relevance.

The hereditary process – in the heterosexual model – was conceptualised around the equality of the paternal and maternal contribution: the chromosomes of the germ cells. An array of hypotheses and experimental findings was necessary to stabilise this equality claim. Their behaviour during cell division, germ cell formation, fertilisation and embryonic development made the chromosomes the ideal cellular component to harbour the newly rediscovered hereditary factors, which followed the Mendelian laws. And, the Mendelian laws of inheritance also postulated – per assumption and experimental design – the equal contribution of male and female parent. The gene as the elementary unit of heredity was conceptualised within this framework which excluded a priori a possible maternal inheritance transmitted via the cytoplasm.

But, proving equality was a tricky problem at the level of the gendered germ cells. First there was the undeniable morphological size difference: the spermatozoon contributed only chromosomes to the next generation, whereas the egg cell contributed chromosomes and the cytoplasm, which contained all the substances needed for the cell's function, division and subsequent differentiation. Even more, this female cytoplasm was active – it reorganised the chromosomes during ontogenesis.[37] For the process of cell differentiation during ontogenesis, a mechanism was needed which guaranteed that only certain parts of the hereditary material, that is parts of the chromosomes, were present in different cell lines so that they could differentiate into muscles, nerve or liver cells, etc.[38] According to Boveri's and his female co-workers' findings in the years between the late 1880s and 1910, the cytoplasm reorganised the chromosomes during ontogenesis.[39] In the germ line, however, the chromosomes were not affected by plasmatic activity; here, following Weismann's germ line theory, the hereditary material was transmitted unchanged to the next generation of organisms. This assumption guaranteed that male influence to the next generation equalled the female, and it made the findings about the chromosomes compatible with the new experimental approaches of Mendelian genetics. But, Boveri could not propose a mechanism by which the 'female' cytoplasm stayed inactive in the germ line.

In Boveri's work, the two gendered germ cells were seen as mutually dependent on each other.[40] There was no conflict of different reproductive strategies as current biological thought assumes. Around 1900, the tendency to perform cell division was inhibited in both the egg cell and in the spermatozoon when apart. Both cells needed each other to guarantee procreation, which was regarded as the raison d´être of all life forms. However, there were contemporary observations and experiments on parthenogenesis, according to which the egg cell could start dividing and developing into a full-grown organism, without fusing with a spermatozoon. Due to its lack of cytoplasm, however, the spermatozoon was very unlikely to divide into two cells and start procreation on its own. A gendered difference remained.

Genetic concepts in Boveri's work were thus gendered at several levels: with the help of the gendered germ cells, and the use of heterosexual procreation as the model for all hereditary processes, the cell and its components were ordered by gender. The 'female' egg cell contributed chromosomes and cytoplasm and the 'male' spermatozoon contributed chromosomes to the next generation. Therefore, only the chromosomes could guarantee a paternal contribution to heredity equalling the maternal. Identifying the chromosomes as the definitive hereditary substance ensured gender equality (rather than female preponderance) in the process of inheritance. The paternal contribution matched the maternal only if the cytoplasm was deemed irrelevant in heredity.

The cytoplasm became female and subordinate. Within the cell a gendered hierarchy was established. In Boveri's work the cytoplasm was still powerful and active, but only during the embryonic development of the organism. Here was the realm of female influence, which could be framed in the classic notion of nutrition, care and guidance.[41] The cytoplasm did not contribute hereditary traits to the next generation. Only the chromosomes were seen as the cellular units, which could 'imprint' hereditary properties onto the cell and organism. Symbolically, the chromosomes became male, even though both egg and sperm contained them. For the following decades, this hierarchical gendered order of the cell and hereditary processes created a blind spot for genetics, which focused on the genes in the chromosomes only. Processes of cytoplasmatic organisation of the 'hereditary substance' have since slowly come back into focus under the name of epigenetics. The older concepts of the gene as the only determining physical unit in the DNA can now be questioned in a new way.[42] However, this is not necessarily the consequence of a clandestine feminist revolution brought about by a 'better, gender conscious approach' in genetics. It is simply the result of new capacities to calculate and model complex interactions of molecular components of the chromosomes and cytoplasm of the cell.

Interactive or hierarchical binary?

In Boveri's last publication the chromosomes were not perceived as the all-powerful entities controlling the cell and the organism. There was always collaboration and interdependence between the chromosomes and the cytoplasm, especially during development. But this understanding did not become mainstream in genetic research and thought.[43] The investigation into heredity was reduced to cross-breeding experiments in the search for genes on chromosomes. For this approach Thomas Hunt Morgan's (1866–1945) research group, which started their chromosome mapping project with the fruit fly Drosophila melanogaster in 1911, became particularly important. The model organism Drosophila was not as well-suited to investigating the interaction of chromosomes and cytoplasm, as Boveri's sea urchins were. But, cross-breeding Drosophila allowed for the establishment of a theory of the gene as sites on the chromosome.[44] This new experimental approach was highly productive; it created a dramatic momentum and came to dominate zoological genetics. With genetics evolving, an initially cooperative binary gender order was transformed into a hierarchical and asymmetric one; it was transformed into a classic dualism, where one part of the two – the chromosome (and after 1953, the DNA) – became the active representative of the whole cell or organism, whereas the cytoplasm became the subordinate female and passive other.[45]

There is an irony to this story. The new genetic gender equality, established with the help of the chromosomes to safeguard men's equal contribution to the next generation, was used in other realms such as political efforts to gain women's equality. In the early decades of the twentieth century, female doctors and geneticists, and also male geneticists, even argued in favour of women's admission to universities based on the new results of genetics. Women, they argued, could no longer be seen as inferior; they inherited half of their faculties from their fathers – as did their brothers.[46]

Chromosomes and the binary, inheritable sex difference

The identification of chromosomes as the hereditary material had another effect on biology. The chromosomal theory of heredity became the basis for the new genetic interpretation of sex difference in 1905 by Nettie M. Stevens and Edmund Wilson.[47] Wilson was an old friend of the Boveris, and Stevens had worked in Boveri's laboratory shortly before she proposed the new interpretation. Both had first hand knowledge of the work on chromosomes as hereditary material. In the case of insects, a difference in the number or size of the chromosomes could be correlated with the difference between male and female organisms. Depending on the species chosen for investigation, two types of germ cells could be identified which differed in the amount of chromosomal substance they transmitted; either the size or the number of chromosomes differed between them. In most of the species investigated, two types of spermatozoa were present; in some species two types of egg cells were produced. Male and female offspring were now viewed as the result of an accidental combination of germ cells and their chromosomes during fertilisation. Sex difference became genetically based and binary, an either-or difference.

With this new interpretation men and women could be seen as binary alternatives. Some could see them as equals; for others there was still the possibility to see men as the fully developed version of man and women as the lesser one. But the important novelty was that being a man or a woman could now be seen as the result of a chromosomal lottery with women getting forty-eight and men getting forty-seven chromosomes.[48] The new theory of chromosomal sex determination had another considerable advantage for women in the asymmetric gender order of the time: women could no longer be held responsible if they gave birth to girls only. Now they could claim that 'boy or girl' depended on the actual chromosomal constitution of the 'male' spermatozoon, which took part in fertilisation. The father 'decided' on the sex of the child.

The new binary concept of chromosomal sex difference became crucial for Morgan's above-mentioned gene mapping project, which produced the first theory of the gene as discrete units in a linear arrangement on the chromosomes. In this respect the concept was highly productive, while it also helped to stabilise the binary gender order within the cell. But, it also created a new problem for biology as older embryological concepts of sex difference could not be incorporated into genetics. Embryology was based on studies in comparative anatomy in the nineteenth century that saw sex difference as the result of development from a primordial, bisexual embryo. In this older view, all organisms had a bisexual potential, whereas the new genetic model based on chromosomal difference postulated a binary either-or sex difference from the moment of fertilisation.

'Intersexes' – reconciling sex difference in embryology and genetics

Richard Goldschmidt, a member of the same German research community as Boveri, was successful in developing a genetic interpretation of sex determination compatible with embryological concepts.[49] In 1913 he started cross-breeding experiments to investigate the new heredity of sex difference. He used various geographic populations – or 'races' in the terminology of taxonomists – of the gypsy moth Lymantria dispar prevalent in Europe and Japan. Certain combinations of different populations resulted in offspring which no longer showed clear signs of being male or female, such as wing pigmentation or size and morphology of the antennae. Goldschmidt termed these specimen 'intersexes'. He claimed that he could produce all stages of intersexes between male and female by choosing the appropriate populations for his experiments. He postulated the existence of male and female genetic factors, which were responsible for sex determination within one organism. Male and female organisms would have both male and female genetic factors situated on the chromosomes and in the cytoplasm. Their mixture, strength and the timing of activity determined male or female or intersexed identity.[50] Goldschmidt refined his model in the 1920s and succeeded in reconciling the newer genetic and older embryologic concepts of sex determination. According to his interpretation every individual organism and even each of its cells had the potential to develop in the male or female direction, with all intermediate stages possible. In Goldschmidt's model, masculinity and femininity were not two exclusive binary possibilities, but rather admixtures.[51] There was no pure masculinity or femininity: each 'Geschlecht' (sex), according to Goldschmidt, was a mixture of both 'Geschlechter' (sexes), with one of the two prevailing.

Goldschmidt started to refer to his findings in the context of political debates about male homosexuality and hermaphroditism during the First World War. Joining his colleagues from sexology, such as Magnus Hirschfeld (1868–1935), he argued in favour of the decriminalisation of homosexuality as one of many natural ways of being. Hermaphrodites should not be assigned one of two sexes, as they simply did not fit into those categories. Goldschmidt's genetic model of sex determination allowed him to formulate this novel view. However, even this argument still had the potential to pathologise extreme forms of intersexuality, and it could still incorporate a claim of male dominance. The crucial, and at his time highly controversial point was that there was no femininity-free masculinity: each sex contained elements of the other.

Goldschmidt's right-wing and völkish colleagues found ways to use his scientific work for completely different political ends in the 1920s. They took his results from the cross-breeding experiments as scientific foundation for their antisemitic and anti-feminist political agenda by arguing for the preservation of the racial purity of the Nordic race and of a strictly binary gender order. The racial hygienist Fritz Lenz (1887–1976) was one of the key figures in this process. He later became a leading human geneticist of the Nazi era, when he was appointed head of department for eugenics at the Kaiser-Wilhelm Institute for Anthropology, Human Heredity and Racial Hygiene in Berlin. After 1945 he was appointed the first professor of human genetics in West Germany.

Lenz was an ambitious young medical doctor and dedicated to the project of racial hygiene. He started his career in 1912 with a Ph.D. about the sex-linked inheritance of diseases in men and sex determination. Subsequently he worked within the theoretical paradigm Goldschmidt had established. He even cross-bred specimens of the moth Lymantria dispar to investigate sex determination and the creation of intersexed animals.[52]

For Lenz and his völkish colleagues, the Nordics or Aryans were the most highly developed race. They were characterised by the most pronounced physical and mental difference between men and women, which was marked politically by their difference in their legal status. Lenz saw the blurring of a clear binary human gender order, as it unfolded in the years of the Weimar Republic, as a dangerous sign of racial degeneration. Using the results of Goldschmidt's cross-breeding experiments, Lenz claimed that miscegenation ('Rassenmischung' or even 'Rassenschande') was the genetic cause for this process. As Germany no longer had colonies after 1919, miscegenation was mainly seen as occurring in the marriages between so-called Aryans and people of Jewish descent. During the later years of the German Empire, the idea had circulated already that German-Jewish marriages caused degeneration by effeminising men and masculinising women, thus leading to the decline in birth rate and weakening the State. This trope had become a key element of antisemitic, anti-democratic and anti-feminist political thought before the First World War.[53] In the 1920s, science, and especially genetics, could be used to support it. According to Lenz and his allies, the highly visible New Woman of the Weimar republic, female suffrage and the efforts to invent new gender orders beyond the heterosexual matrix of strict binaries could be understood as a genetic process of degeneration. Marriage bans were argued to be the necessary consequences; they were first put in place with the Nuremberg laws in 1935. This was the point at which Goldschmidt found himself legally classified as Jewish, deprived of his German citizenship; his children faced marriage bans.

Goldschmidt's genetic concept of sex determination and its experimental foundation were used for opposite political agendas: in favour of diversity in gender and sexual orientation and in support for racist and anti-feminist efforts. For genetic research, the case was different. Lenz did not use Goldschmidt's gene concept, which was based on the study of the inheritance of sex difference. In Goldschmidt's view genes did not necessarily cause the same phenotype under all circumstances. Like the genetic factors for masculinity and femininity, all genetic factors had to be conceptualised as differing in 'strength'; they were not stable and independent of their context.

This concept of the gene was unacceptable for Lenz and his colleagues who aimed at a new genetics-based racial anthropology. They needed a gene concept where the gene was reliable and always produced the same effect. Otherwise racial traits would not necessarily reappear in following generations; racial difference would blur like sex difference, especially in a case of 'miscegenation'. Goldschmidt's genes not only made the two sexes rather fluid and connected by a continuum of intersexes, they were also not suitable to guarantee the stable inheritance of racial characters. Consequently, Lenz rejected Goldschmidt's gene concept, but he used some results of Goldschmidt's experiments for the scientific foundation of his political concepts of a social order, which demanded clear distinctions and hierarchies between men and women or people classified as members of different races.

Sex hormones and the binary again

A third experimental and conceptual approach to the problem of sex determination was the search for 'sex hormones' and their function in the organism of vertebrates.[54] The German biochemist Adolf Butenandt started the search for sex hormones in mammals and humans in the mid-1920s in collaboration with his future wife and technical assistant, Erika von Ziegner. At that time he was a young biochemist at the University of Göttingen whose work was supported by the Berlin pharmaceutical company, Schering-Kahlbaum.[55] Contemporary endocrinologists and biochemists used a binary model of sex difference; male hormones were seen as antagonists of the female hormones.[56] This model was based on the assumption that the male or female gonads produced the respective hormones that determined the sex of the organism. Castration experiments had shown that without gonads the sex characters of the organism disappeared. Substituting for lost gonads by implanting gonads or injecting gonadal extracts could reconstitute these sexual characters. Testes were seen as the production site of male hormones, and ovaries as the origin for female hormones. Many disciplines competed in the research on these substances, which promised to become powerful tools as drugs, once they could be chemically isolated and identified. Biochemists, physiologists, gynaecologists, embryologists and others used gonadal extracts or urine for their experiments, which led to controversial results and once again challenged the initial assumption of a binary order of female and male hormones.[57] Male organisms could produce female hormones and male hormones could be transformed into female hormones and vice versa in the biochemical laboratory. As soon as synthetic hormones could be produced in large quantities in the mid-1930s, experiments proved the feminising effects of supposedly male hormones and the masculinising effects of supposedly female hormones.[58] The seemingly simple categorisation of these hormones into male and female had become questionable.

Butenandt is especially interesting to investigate in this context because we can see clearly how he preserved the initial hormonal gender order, leaving it unchanged in the face of contradictory experimental evidence. Starting with the assumption of a binary order of the hormones, he isolated a 'female' hormone (named Progynon) in the late 1920s, and in collaboration with his assistant Ulrich Westphal, a corpus lutem hormone responsible for pregnancy in the early 1930s (Progesterone); he completed the hormonal set with the isolation of a hormone identified as male (Androsterone). In 1939 he was awarded 'the Nobel prize in Chemistry for the work on the sex hormones'.[59]

To identify the chemically isolated hormones as male or female and to identify their efficacy, specially designed animal tests were needed. These animals were transformed into instruments of measurement. They received injections of hormonal extracts, and then the effects on certain tissues helped to identify the extract containing the most effective hormone. Female hormones could be seen by their effect on the vaginal tissue of castrated mice, whereas the comb growth of capons, measured in millimetres, indicated the effects of the male hormone.[60] Butenandt was not interested in the physiology of the hormones; his experimental approach was not suited to understanding their role in sex determination during development. He was in search of a drug and focused on the identification and isolation of substances. He pursued the crystallisation of male and female hormones as those substances that proved to be the most effective in his experimental settings. By design, the experiments merely confirmed the existence of male or female hormones as expected. The isolated and later synthesised substances were to be sold as medication – to compensate for gendered frailties, be it weakening physical or mental features of masculinity or femininity.

With hormones available in pure form and larger quantities, new experiments showed the paradoxical effects of the supposedly male or female hormones even in Butenandt's laboratory. Despite his own and other scientists' results he continued to identify all sex-related hormones as male, female or pregnancy hormones, even as late as the 1950s. His perseverance is even more striking, as he could have used Richard Goldschmidt's model of sex determination according to which a mixture of male and female sex-determining substances, in combination and respective balance, determines the organism's male and female physical features. Indeed, Goldschmidt had integrated the new biochemical findings on the sex hormones (by Butenandt and others) into his model of sex determination by the late 1920s, but Butenandt did not refer to Goldschmidt's model.[61] In 1936 Butenandt nearly became the colleague of Goldschmidt, when he took up the position as the Director of the Kaiser Wilhelm Institute for Biochemistry in Berlin, whose former Jewish director Carl Neuberg (1877–1956) had been sent into forced retirement.[62] In the same year Goldschmidt was himself forced to emigrate, and he lost his citizenship and the position as head of department at the Kaiser Wilhelm Institute of Biology. Both institutes were neighbours in the Berlin suburb Dahlem; Butenandt and Goldschmidt belonged to the same prestigious scientific community, which had, however, excluded its Jewish members by 1936.

It is apparent that there were political reasons why Butenandt did not accept Goldschmidt's model. The model of every higher organism being a mixture of male and female characters had ultimately become branded a 'Jewish model'. By the mid 1930s it was mostly Jewish scientists, now in emigration, who developed and used it. The model was not compatible with Butenandt's right-wing, völkish concept of masculinity, which had to be pure and not 'contaminated' by feminine features. Butenandt persisted with his concept; there was no more scientific opposition to fear, and in the political situation of the time, his model was deemed politically correct.

But, even without these political motives, it would have been difficult for Butenandt to give up his model and change his experimental approach. Such a change would have meant giving up the leading role as a biochemist, crystallising and identifying organic substances, and handing scientific leadership over to physiology or embryology where the development of sex difference in organisms could be studied with different methods and concepts. He did not do this. Instead, his solution was to give up research on hormones by the mid 1930s and look for a new epistemic object. He continued with his experimental approach, which henceforward aimed at the identification and crystallisation of other 'active principles' as chemical agents. He and his research group focussed on genes and viruses and other highly powerful substances and tried to identify them chemically.[63]

Conclusion

The Butenandt case clearly shows how political reasons encouraged the acceptance and rejection of a particular scientific model of sex differences. It also shows that there were constraints within particular disciplinary traditions and experimental systems, which made a change of approach extremely difficult for the scientists involved. The blunt pressure of politics increased Butenandt's power within the scientific community and also shielded him from criticism. The combination of all these factors added to the stabilisation within German science of a concept of sex difference and sex determination, which could have been challenged by a different disciplinary approach existing in principle at the time. But virtually no powerful research group with the appropriate support or funding existed.

In the works of Boveri and Goldschmidt, experimental settings and commitments to disciplinary traditions also set the stage for the gender concepts possible in genetics. This material and practical framework is important in explaining why certain concepts were developed and applied. These concepts sometimes moved in opposite directions: an equality claim at the level of germ cells' chromosomes stabilised a gendered hierarchy within the cell and the gendered agenda of genetics. The new chromosomally determined sex difference had the same effect, and it disconnected genetics from embryology at a key point. If we include among explanatory factors the political salience of the different models, things become even more complicated: the equality claim at the level of the chromosomes helped to support a new notion of male equality in reproduction, which countered a perceived superiority of women. However, in politics this new genetic equality could be used to argue in favour of women, who had not reached political, social, legal and economic equality with men. Research on chromosomal sex determination could be called upon to protect women from blame when they gave birth to a child of the wrong gender, but it also supported the notion of a binary, discontinuous sex difference. The concept of a sex difference as proposed by Goldschmidt defined intermediate stages between male and female as natural and reconnected embryology and genetics. The political uses of these findings again encompassed opposite tendencies – liberalisation on the gender/sexuality front and support for racist, antisemitic and anti-feminist politics.

Is there a personal component to this political pattern? Do the individual scientists matter when certain experimental systems and disciplinary traditions of thought have their own dynamics, when scientific work determines which (scientific) gender concepts can be developed and used? Do scientists' personal gender-political convictions count at all? The era in question here saw political debates on gender difference, moves toward political and educational equality, challenges to a binary, hierarchical gender order and also efforts to reinstall it. At the social level there was no hegemony of gender concepts; nevertheless, the general framework of male dominance was not fundamentally transformed. However, I think it makes sense to assume that the choice of scientific questions and experimental approaches is not arbitrary. Scientific fields are fields where authority, respect and power are distributed in rather uneven ways. Therefore gender orders are part of this field as well. The choice of a particular disciplinary field and approach by a particular person may well depend on the tolerance and freedom offered by the members of this field with regards to possible gender orders. This may contribute to the connections between the social gender order at the scientific workplace and the scientific gender orders developed in this place – it is a loose, contradictory and very dynamic relationship, and not a simple causal one.

Notes

1. See for example the different approaches of Ludwik Fleck, *Genesis and Development of a Scientific* Fact (1935; repr. Chicago: University of Chicago Press, 1979); Karin Knorr-Cetina, *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science* (Oxford: Pergamon Press, 1984); Bruno Latour and Steve Woolgar, *Laboratory Life: The Construction of Scientific Facts* (Princeton: Princeton University Press, 1979); Hans-Jörg Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford: Stanford University Press, 1997).
2. Sarah S. Richardson, 'When Gender Criticism Becomes Standard Scientific Practice: The Case of Sex Determination Genetics', in Londa Schiebinger (ed.), *Gendered Innovations in Science and Engineering* (Stanford: Stanford University Press, 2008), pp. 22–42.
3. Here I differ from Thomas Laqueur, *Making Sex: Body and Gender from the Greeks to Freud* (Harvard: Harvard University Press, 1990). The one-sex-model was not dead in the 20th century.
4. See for example: Jeanne Boydston, 'Gender as a Question of Historical Analysis', *Gender & History* 20 (2008), pp. 558–83.
5. To make things even more confusing we can find the phrase 'gender is engrained in our genes' in popular parlance, which is exactly the opposite of what was intended with the use of the term 'gender'. On the trivialisation of 'gender' see Joan Scott, 'Gender: Still a Useful Category of Analysis?', *Diogenes* 225 (2010), pp. 1–5.
6. It was not feminist scholarship which invented the distinction. In 1955 psychologists at the Johns Hopkins Hospital in Baltimore introduced the term 'gender' to distinguish between the body and the psychosexual development of children with ambiguous genitals, which were surgically changed to a female or male 'normality'. This approach was part of a long term – and finally strongly criticised – medical experiment which should show the malleability of social or psychological gender identities and their relative independence from the body. See: Ulrike Klöppel, *XX0XY ungelöst. Hermaphroditismus, Sex und Gender in der deutschen Medizin* (Bielefeld: transcript, 2010), pp. 307–36.
7. Just to mention some classics: Ruth Hubbard (ed.), *Women Look at Biology Looking at Women: A Collection of Feminist Critiques* (Boston: Hall, 1979); Fischer-Homberger, *Krankheit Frau und andere Arbeiten zur Medizingeschichte der Frau* (Bern: Huber, 1979); Ruth Bleier, *Science and Gender: A Critique of Biology and its Theories on Women* (New York: Pergamon, 1985); Donna Haraway, *Primate Visions: Gender, Race, and Nature in the World of Modern Science* (New York: Routledge, 1989); Emily Martin, 'The Egg and Sperm: How Science has Constructed a Romance Based on Stereotypical Male-Female Roles', in Evelyn Fox Keller and Helen E. Longino (eds), *Feminism and Science* (Oxford, New York: Oxford University Press, 1996), pp. 103–17; Anne Fausto-Sterling, 'The Bare Bones of Sex: Part 1 – Sex and Gender', *Signs* 30 (2005), pp. 1491–527; Judith Butler, *Gender Trouble: Feminism and the Subversion of Identity* (New York: Routledge, 1990).
8. For example: Claudia Honegger, *Die Ordnung der Geschlechter. Die Wissenschaften vom Menschen und das Weib, 1750–1850* (Frankfurt: Campus, 1991).
9. Most prominent: Londa Schiebinger, *Gendered Innovations in Science and Engineering* (Stanford: Stanford University Press, 2008); Londa Schiebinger, *Has Feminism Changed Science?* (Cambridge, London: Harvard University Press, 1999).
10. Marcellina's aria 'Il capro e la capretta' in Mozart's *Le Nozze di Figaro* (1786) reflects this conviction of feminist Enlightenment thought.
11. Scott F. Gilbert and Karen A. Rader, 'Revisiting Women and Feminism in Developmental Biology', in Angela Creager, Elizabeth Lunbeck and Londa Schiebinger (eds), *Feminism in Twentieth-Century Science:*

Technology, and Medicine (Chicago: University of Chicago Press, 2001), pp. 73–97. See also Evelyn Fox Keller, 'Developmental Biology as a Feminist Cause?' in Sally Gregory Kohlstedt and Helen E. Longino (eds), 'Women, Gender, and Science. New Directions', *Osiris* 12 (1997), pp. 16–28.

12. Richardson, 'Gender Criticism'.
13. Ruth Hubbard, 'Gender and Genitals: Constructs of Sex and Gender', in Andrew Ross (ed.), *Science Wars* (Duke University Press, 1996), pp. 168–79.
14. Hubbard, 'Gender', p. 178.
15. On the medical history of the creation of a binary sex/gender order, including current debates on intersexed people, see Klöppel, *XX0XY*.
16. See also Hubbard's outspoken anti-racist work. Ruth Hubbard, 'Race & Genes', Social Sciences Research Council (2006), <http://raceandgenomics.ssrc.org/Hubbard>.
17. Donna Harraway, 'Primatology is Politics by Other Means', *Proceedings of the Biennial Meeting of the Philosophy of Science Association*, (1984), pp. 489–524; Donna Haraway, 'Investment Strategies for the Evolving Portfolio of Primate Females' in Mary Jacobus, Evelyn Fox Keller and Sally Shuttleworth (eds), *Body/Politics: Women and the Discourse of Science* (New York: Routledge, 1990), pp. 139–62.
18. See for example: Theresa Wobbe (ed.), *Frauen in Akademie und Wissenschaft. Arbeitsorte und Forschungspraktiken 1700–2000* (Berlin: Akademie Verlag, 2002); Karin Hausen, 'Wirtschaften mit der Geschlechterordnung. Ein Essay', in Theresa Wobbe (ed.), *Zwischen Vorderbühne und Hinterbühne. Beiträge zum Wandel der Geschlechterbeziehungen in der Wissenschaft vom 17. Jahrhundert bis zur Gegenwart* (Bielefeld: transcript, 2003), pp. 83–107; Margaret W. Rossiter, 'Which Science? Which Women?', in Sally Gregory Kohlstedt and Helen E. Longino (eds), 'Women, Gender and Science. New Directions', *OSIRIS* 12 (1997), pp. 169–85.
19. For a more detailed account see Helga Satzinger, *Differenz und Vererbung. Geschlechterordnungen in der Genetik und Hormonforschung, 1890–1950* (Cologne, Weimar, Vienna: Böhlau, 2009). See also: Helga Satzinger, 'The Chromosomal Theory of Heredity and the Problem of Gender Equality in the Work of Theodor and Marcella Boveri', in *Conference: A Cultural History of Heredity III: 19th and Early 20th Centuries*. Prepring 294, Max Planck Institut für Wissenschaftsgeschichte, Berlin (2005), pp. 102–14; Helga Satzinger, 'Theodor and Marcella Boveri: Chromosomes and Cytoplasm in Heredity and Development', *Nature Reviews Genetics* 9 (2008), pp. 231–8; Helga Satzinger, 'Racial Purity, Stable Genes, and Sex Difference: Gender in the Making of Genetic Concepts by Richard Goldschmidt and Fritz Lenz, 1916 to 1936', in Susanne Heim, Carola Sachse and Mark Walker (eds), *The Kaiser Wilhelm Society for the Advancement of Science under National Socialism* (Cambridge: Cambridge University Press, 2009), pp. 145–70.
20. On Butenandt's career in Nazi Germany see: Walter Schieder and Achim Trunk (eds), *Adolf Butenandt und die Kaiser-Wilhelm-Gesellschaft. Wissenschaft, Industrie und Politik im 'Dritten Reich'* (Göttingen: Wallstein, 2004).
21. Marilyn Bailey Ogilvie and Clifford J. Choquette, 'Nettie Maria Stevens (1861–1912): Her Life and Contributions to Cytogenetics', *Proceedings of the American Philosophical Society* 125 (1981), pp. 292–311; Stephen G. Brush, 'Nettie M. Stevens and the Discovery of Sex Determination by Chromosomes', *ISIS* 69 (1978), pp. 162–72.
22. Anne Fausto-Sterling, *Sexing the Body: Gender Politics and the Construction of Sexuality* (New York: Basic Books, 2000); Nelly Oudshoorn, 'On Measuring Sex Hormones: The Role of Biological Assays in Sexualising Chemical Substances', *Bulletin of the History of Medicine* 64 (1990), pp. 243–61; Nelly Oudshoorn, 'Endocrinologists and the Conceptualisation of Sex, 1920–1940', *Journal of the History of Biology* 23 (1990), pp. 163–86; Nelly Oudshoorn, *Beyond the Natural Body: An Archeology of Sex Hormones* (New York: Routledge, 1994); Chandak Sengoopta, 'Glandular Politics: Experimental Biology, Clinical Medicine, and Homosexual Emancipation in Fin-de-Siècle Central Europe', *ISIS* 89 (1998), pp. 445–73; Chandak Sengoopta, 'The Modern Ovary: Constructions, Meanings, Uses', *History of Science* 38 (2000), pp. 425–88; Chandak Sengoopta, *The Most Secret Qintessence of Life: Sex, Glands, and Hormones, 1850–1950* (Chicago: University of Chicago Press, 2006).
23. See especially the work of Magnus Hirschfeld and 'The First Institute for Sexual Science (1919–1933)' on the website of the Magnus-Hirschfeld-Gesellschaft, <http://www.hirschfeld.in-berlin.de>.
24. Oudshoorn, *Archaeology*; Oudshoorn, 'Endocrinologists'.
25. Fausto-Sterling, *Sexing*, p. 193.
26. Patricia M. Mazón, *Gender and the Modern Research University: The Admission of Women to German Higher Education, 1865–1914* (Stanford: Stanford University Press, 2003); Johanna Bleker (ed.), *Der Eintritt der Frauen in die Gelehrtenrepublik: Zur Geschlechterfrage im akademischen Selbstverständnis*

und in der wissenschaftlichen Praxis am Anfang des 20. Jahrhunderts (Husum: Mattiesen, 1998); Annette Vogt, *Vom Hintereingang zum Hauptportal. Lise Meitner und ihre Kolleginnen an der Berliner Universität und in der Kaiser-Wilhelm-Gesellschaft* (Stuttgart: Franz Steiner Verlag, 2007); Hiltrud Häntzschel and Hadumod Bußmann (eds), *Bedrohlich gescheit. Ein Jahrhundert Frauen und Wissenschaft in Bayern* (Munich: C. H. Beck,1997).

27. Satzinger, *Differenz*, pp. 51–84.
28. Satzinger, *Differenz*, pp. 213–16 on Mathilde Hertz in Berlin; pp. 228–35 on Käte Pariser and Anne-Marie du Bois; pp. 235–7, 238–46 on the general situation of women.
29. Satzinger, *Differenz*, pp. 243–6 on Aloha Hannah Alava and Leonie Kellen Piternick.
30. Satzinger, *Differenz*, pp. 239–43, 246. On McClintock see Evelyn Fox Keller, *A Feeling for the Organism: The Life and Work of Barbara McClintock* (New York: Freeman 1983) and Nathaniel Comfort, *The Tangled Field: Barbara McClintock's Search for Patterns of Genetic Control* (Cambridge: Cambridge University Press, 2001). Both interpret Goldschmidt's support for McClintock as disadvantageous for her standing in the scientific community. On the Nobel Prize see: 'The Nobel Prize in Physiology or Medicine 1983', <http://www.nobelprize.org/nobel_prizes/medicine/laureates/1983/>.
31. Satzinger, *Differenz*, pp. 203–09.
32. Satzinger, *Differenz*, pp. 299–338, 350–72.
33. For further detail please consult Satzinger, *Differenz*, pp. 85–141; Satzinger, 'Chromosomal Theory'; Satzinger, 'Theodor and Marcella Boveri'.
34. I do not go further into the more than obvious metaphoric gendering of those cellular processes where mother cells divide into daughter cells. Giving birth was the model for cellular procreation, and germ cells became male and female. For the modelling of molecular genetics on heterosexual procreation; see: Angela N. H. Creager, 'Mapping Genes in Microorganisms', in Jean Paul Gaudillière and Hans-Jörg Rheinberger (eds), *From Molecular Genetics to Genomics: The Mapping Cultures of Twentieth-Century Genetics* (London, New York: Routledge, 2004), pp. 9–41; Roberta Bivins, 'Sex Cells: Gender and the Language of Bacterial Genetics', *Journal of the History of Biology* 33 (2000), pp. 113–39.
35. There were some exceptions, though. In some species the spermatozoon also contributed a particle called centrosome, which was necessary for the cellular apparatus that distributed the chromosomes into the daughter cells during cell division. However, there was never cytoplasm in the spermatozoon.
36. On the recent miniaturisation of y-chromosomes: Richardson, 'Gender Criticism'.
37. This active role has been overlooked so far in recent gender and science studies, see Evelyn Fox Keller, *Refiguring Life: Metaphors of Twentieth-Century Biology* (New York: Columbia University Press, 1995); Bonnie B. Spanier, *Im/partial Science: Gender Ideology in Molecular Biology* (Bloomington: Indiana University Press, 1995).
38. Today this process is explained by gene regulation while the chromsomes and the DNA in the chromosomes are not changed structurally.
39. Those were the American women scientists, working as visiting scholars at the laboratory of Boveri: Nettie M. Stevens, Alice M. Boring, Florence Peebles and Mary J. Hogue.
40. Boveri's description is obviously analogous to a bourgeois married couple of his time. For a comparison, see the 'romance' of egg cell and spermatozoon in more recent biology textbooks as analysed by Emily Martin, 'Egg and Sperm'. Today's sociobiologists see conflicting reproductive strategies of egg and sperm at work, there is no longer cooperation.
41. The framework of the egg as the female nutritional contribution has been used for a long time. See Esther Fischer-Homberger, *Harvey's Troubles with the Egg* (Sheffield: European Association for the History of Medicine and Health Publications, 2001). See also Keller, *Refiguring Life*; and Spanier, *Science*.
42. Evelyn Fox Keller, *The Century of the Gene* (Cambridge, London: Harvard University Press, 2000).
43. In the German context of the 1920s the cytoplasm-nucleus interaction remained relevant for geneticists. Jonathan Harwood, *Styles of Scientific Thought: The German Genetics Community 1900–1993* (Chicago, London: University of Chicago Press, 1993). With Lysenkoism starting to dominate Russian genetics after the War, scientific questions concerning the cytoplasm in genetics became more or less a taboo in the West.
44. Robert E. Kohler, *Lords of the Fly: Drosophila Genetics and the Experimental Life* (Chicago: University of Chicago Press, 1994); Hans-Jörg Rheinberger, Jean Paul Gaudillière (eds), *Classical Genetic Research and its Legacy: The Mapping Cultures of Twentieth-Century Genetics* (London, New York: Routledge, 2004).
45. On the philosophical context of this classic hierarchical binary, Cornelia Klinger, 'Feministische Theorie zwischen Lektüre und Kritik des philosophischen Kanons', in Hadumod Bußmann and Renate Hof (eds), *Genus. Gender Studies in den Kultur- und Sozialwissenschaften. Ein Handbuch*, (Stuttgart: Kröner Verlag, 2005), pp. 328–64.

46. Satzinger, *Differenz*, p. 42. Thus far, I have found the geneticist Agnes Bluhm (1862–1943); the physicist Hope Adams-Lehmann (1855–1916); the zoologists Oscar Hertwig (1849–1922) and Wulf Emmo Ankel (1897–1983) and the Norwegian geneticist Otto Mohr.
47. Brush, 'Stevens'; Ogilvie and Choquette, 'Stevens'.
48. It was not until the 1950s that scientists identified the number of human chromosomes as forty-six in men and women: with men having one smaller 'sex chromosome', called the y-chromosome.
49. For a more detailed and referenced account, see Satzinger, 'Racial Purity'; Satzinger, *Differenz*, pp. 154–292.
50. See Richardson, 'Gender Criticism' for a comparison with the most recent model.
51. Goldschmidt's concept was not the only one of his time to question a binary, discontinuous sex difference. His colleague at the KWI for Biology, Max Hartmann (1876–1962), saw various stages of intersexuality in the mating behaviour of single cell organisms and developed his theory of 'sexuality' including intersexual forms. The differences with Goldschmidt's theory lay in the explanation of the causes of sex development. See Heng-an Chen, *Die Sexualitätstheorie und 'Theoretische Biologie' von Max Hartmann in der ersten Hälfte des zwanzigsten Jahrhunderts* (Wiesbaden: Franz Steiner Verlag, 2003).
52. Fritz Lenz, *Über die krankhaften Erbanlagen des Mannes und die Bestimmung des Geschlechts beim Menschen. Untersuchungen über somatische und idioplasmatische Korrelation zwischen Geschlecht und pathologischer Anlage mit besonderer Berücksichtigung der Hämophilie* (Jena: Gustav Fischer Verlag, 1912); Fritz Lenz, 'Erfahrungen und Entartung bei Schmetterlingen', *Archiv für Rassen- und Gesellschaftsbiologie* 14 (1922), pp. 249–301.
53. Ute Planert, 'Reaktionäre Modernisten. Zum Verhältnis von Antisemitismus und Antifeminismus in der völkischen Bewegung', *Jahrbuch für Antisemitismusforschung* 11 (2002), pp. 31–51.
54. For detailed accounts of this research, see endnote 22.
55. Satzinger, *Differenz*, pp. 293–338, 373–400.
56. Oudshoorn, *Natural Body*, pp. 22–30; Fausto-Sterling, *Sexing*, pp. 158–94. The most prominent representative of this approach was Eugen Steinach (1861–1944) who, with the help of Schering-Kahlbaum's gonadal extracts performed experiments with animals.
57. Oudshoorn, 'Natural Body', pp. 25–30; Sengoupta, *Quintessence*, pp. 136–9; Fausto-Sterling, *Sexing*, pp. 170–94.
58. For these contradictory findings in Butenandt's laboratory see Satzinger, *Differenz*, pp. 385–93.
59. See the website of the Nobel Foundation <http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1939/press.html>. Due to the political circumstances, the German authorities did not allow him to accept the prize. Butenandt shared the prize with the Swiss biochemist Leopold Ruzicka.
60. This is a rather crude simplification of the process. For more details on Butenandt's approach, see Satzinger, *Differenz*, pp. 317–18, 320–25, 327.
61. Satzinger, *Differenz*, pp. 373–400.
62. Satzinger, *Differenz*, pp. 333–6.
63. Satzinger, *Differenz*, pp. 401–23.