The Entanglement of Gender and Physics: Human Actors, Work place Cultures, and Knowledge Production

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Research in an area that might be called gender and physics lies neither in the focus of science studies nor in the centre of gender studies. However, there is a rich tradition of interdisciplinary research that studies the entanglement of gender and physics from different perspectives. In this review article, I give a survey on this inadequately discussed research area by presenting selected examples of often-cited as well as internationally less known literature. Furthermore, I propose a systematisation of three different dimensions, comprising research on human actors, work place cultures, and knowledge production in physics. In so doing, I uncover some achievements and gaps of this interdisciplinary research. Following E. F. Keller (1995), I finally plea for a trading zone for scholars working on the entanglement of gender and physics.

Keywords: Gender Studies, Gender and Physics, Systematisation

Introducing Three Dimensions of Analysis in Regards to Gender and Physics

The body of this paper is a systematisation of the existing literature on gender and physics, introducing research on human actors, work place cultures, and knowledge production in physics. In providing this review I hope to indicate some of the less obvious ways in which physics is gendered. Furthermore, I suggest trans-disciplinary research that brings together expertise from science studies and gender research as a promising way to work on open research questions. First, I start with the presentation of three dimensions of analysis.

For more than three decades scholars of different disciplines have looked critically at natural and technological sciences. The research areas that study natural science while stressing feminist and gender issues are often summarized as Gender and Science (e.g., Keller, 1995) or as Feminist Science Studies (e.g., Mayberry et al., 2001; Wyer et al., 2001). Gender and science or feminist science studies can be understood as a research field that covers research on women in natural and technological sciences as well as analyses of feminist critiques of science and technology. Most of the research done in this area, however, is generated by interdisciplinary efforts that focus on biological sciences and information and communication technologies. First attempts to analyse the entanglement of gender and physics where done in the late 1970s and early 1980s (e.g., Benckert,

1983; Keller, 1977; 1979). There is now a flourishing literature exploring a range of inter- and trans-disciplinary approaches, methods and theories in the area of critical physics research. The systematic analysis of the theories and methodologies employed is still in its infancy (Scheich, 2004) as is the inclusion of approaches coming from physics into the development of new theoretical and methodological concepts (Barad, 2001; 2007). Therefore, a sensible systematisation of feminist and gender studies in physics, in my view, follows the respective epistemological interests and the objects of research being examined. Taking Keller's system 'women in science, science of gender, and gender in science' (Keller, 1995) as well as Schiebinger's system 'women in science, culture of science, and knowledge of science' (Schiebinger, 1999; 2008: 5) into account I suggest the following three dimensions of analysis in regards to gender and physics:

- Human actors in physics
- Work place cultures in physics
- Knowledge production in physics

In the following three sections I will examine these three dimensions with examples of well-known studies of critical physics research as well as some less internationally discussed work by taking into account literature written in English, German, and Swedish. Every dimension is introduced with an example, followed by an overview on this area. Subsequently I draw conclusions on strength and weakness of research in this particular dimension. In the final section I summarize my findings and suggest promising research strategies.

Although I aim to give an insight into gender and science studies for researchers in related fields, my overview is not exhaustive. The ongoing debate in gender studies whether gender and physics research provides any indications for transformations in physics and any instructions on how to practice physics fairly and sustainable in the future (Götschel 2010: 51-52) is not discussed here, because there are no case studies so far that show any impact on physics (Schiebinger, 2008: 20-21). Furthermore, questions on gender and the pedagogy of physics, although important for gender politics in physics (and beyond) are not addressed in this article (e.g., Danielsson 2009: 24-38, Whitten/Burciaga, 2000). Nor will questions of philosophy of science be addressed, although they might deepen the understanding of the entanglement of gender and physics from an epistemological perspective (e.g., Hallberg, 1992; Rolin, 2008; Rouse, 2002). Moreover, because I concentrate on research that deals with both gender and physics from an interdisciplinary perspective, I will exclude outstanding literature from science studies scholars on physics which has not taken into account gender questions as well as prominent literature from gender studies that does not focus on physics.

Human Actors in Physics

Statistics and biographical studies create detailed knowledge in the dimension of analysis on human actors in physics. A selection of studies, which explore the situation of historical and contemporary physicists, will be discussed in this section.
For centuries women have not been a part of professional natural philosophers and physicists. Therefore women's studies researchers as well as some scientists first and foremost started their gender studies by looking at the paucity of women in the field, by studying statistics and by implementing biographical studies of historical and contemporary physicists. Austrian physicist and historian of physics Brigitte Bischof (2003), for example, searched for female physics students and physicists at both the

University of Vienna and the Institute of Radium Research. She discovered the names of more than one hundred female physicists and indicated that between 1910 and 1945 seventy of these women researched for their doctoral theses at the Institute of Radium Research, were employed as assistants, or worked as freelance physicists. The annual proportion of female physicists at the research institute was 22% and increased during World War I to 57%. In her study Bischof advances three reasons why such an extraordinary large proportion of women worked at the Radium Institute. First, like spectroscopy (Tobies, 1996), radioactivity was an up-and-coming branch of physics with not yet rigidly gendered research structures. Second, these women had Marie Curie as a role model; and numerous female employees of the Radium Institutes met the Nobel Prize winner at her Paris laboratory in person. Third and most significantly, Bischof underlines the importance of the institute's first director Stefan Meyer, who considered women to be capable physicists and apt professionals. Rentetzi (2004), in addition, points to the significance of political context as well as experimental culture for the participation of women in radioactivity research. The national socialist dictatorship, however, often stopped the careers of the female physicists on ground of Jewish background, political attitude, or gender (Bischof, 2003). Consequently, the large participation of female physicists in radium research has been faded from the collective memory.

International statistical comparisons show that women appear to be in the minority in physics in many Western industrial countries, but their low percentage is not to be taken as a natural fact. Megaw (1992) was the first to collect data on the percentage of female students and academics of more than 400 physics departments around the world. His statistics showed that the number of university women lecturers in physics worldwide had ranged from under 5% to over 30%. Surprisingly, highly developed industrial countries—such as Japan, Canada, former Western Germany, and Norway—with large physics establishments and strong women's rights movement, had the poorest records of women in physics (Barinaga, 1994; Megaw, 1992). Huge differences also exist across Europe. Statistics of the European Union for the year 2003 show that the percentage of female PhD graduates in physical science in different European countries vary from less than 25% in Austria, Germany, and Switzerland to more than 45% in Italy, Portugal, and Spain (European Commission, 2006: 41-42). Moreover, statistics at a national level reveal that the proportion of female physicists employed in industry, at the university, or in research institutes outside the university as well as in the individual subsections of physics varies considerably in the different subareas (e. g. Benckert, 1997; Whitten, 1996). However, taken on whole these recent statistics on women in physics tell about their current lower proportion and status at all levels in comparison to men, at least in most industrialised countries, and asks for a deeper understanding of the gender gap in physics across countries and cultures.

Biographical studies on historical and contemporary physicists explore the situation of women (and men) working in the field. While publications of scientists and science writers often concentrate on biographies of individual outstanding women physicists, in order to create role models for female science students, historians of science in the last decades framed their biographies with far reaching questions on the working-life and conditions that women physicists encountered in academia, industry, or education. Insightful studies are available

about outstanding female physicists such as the first female professor in Europe, the 18th century physicist Laura Bassi (Ceranski, 1996; Findlen, 1993) or the 1963 Nobel Prize winner Maria Goeppert Meyer, who between her doctoral dissertation at Göttingen University, Germany, in 1930 and her appointment as full professor at the University of California at San Diego, USA, in 1960 worked for 30 years as a poorly paid 'volunteer' in theoretical nuclear physics and during that time developed her nuclear shell model (Moszkowski, 2006, Willisch, 2008). Other findings spotlight on less celebrated physicists such as the researcher in quantum chemistry Hertha Sponer, who from 1920s to the 1960s worked as professor at universities in Göttingen/Germany, Oslo/Norway, and Durham/USA (Maushart, 1997; Tobies, 1996), or the first Swedish female assistant professor Eva von Bahr, a productive scientist in Uppsala and Berlin between 1908 and 1914 (Wennerholm, 2009). Furthermore, Byers and Williams (2006) edited a collection of 40 biographies of women who contributed to twentieth-century physics. Other works examined historical couples and collaborations in physics such as Albert Einstein and Mileva Marć (Trbuhovic-Gjuric, 1982; Pycior et al., 1996) or the occupational group of professional female physicists (Rossiter, 1982; 1995; Sandner, 1999) to understand structural possibilities and obstacles for women in physics. Research on networks of historical and contemporary female physicists revealed the power and limits of their political strategies for institutional change (Götschel, 2001; 2003). Studies on individual research institutes such as the Vienna Institute of Radium Research (Bischof, 2003; Rentetzi, 2004; 2007), the Kaiser Wilhelm Society for the Advancement of Science (Vogt, 2007) or the Cavendish Laboratory at the University of Cambridge (Gould, 1997), focused on places of activity and have recovered the stories of women at laboratories, who until recently were invisible to historians of science (Gould, 1998).

In summary, female physicists are highly represented at the level of biographies. However, literature that is not written in English, is virtually unknown internationally–a case in point is the biography on the cosmopolitan physicist Tatiana Afanaseva-Ehrenfest (Litvinko, 2003), which has been published in Russian. In contrast, research on male physicists from a gender-aware perspective, such as the critical reflection on 'the physics idol' Richard Feynman, are rare (Barad, 1995: 43-44). The research on the shaping of Isaac Newton's image as genius (Fara, 2002), or the study of Michael Faraday's rootedness in working class (Whitten, 2001) can be understood as contributions to masculinity studies. Up to now, most historical and biographic gender studies give portraits of white middle class and upper class scientists without taking into account that various socially and culturally constructed categories–such as gender, race, and class–interact on multiple levels. Some research, however, showed that discriminatory structures frequently are paired with anti-Semitic biases, as in the case of British crystallographer Rosalind Franklin (Delamont 2003; Wiesner 2002: 125-181), or with racist prejudices as in US-American physicist and historian of science Evelynn Hammonds' case (Hammonds/Subramaniam, 2003; Sands, 2001). The quantitative and biographical approach, however, is limited when it comes to understanding structures as well as processes on a larger scale.

Work place Cultures in Physics

Increasingly, historical, sociological, and anthropological studies of scientific institutions such as laboratories, research

groups, subfields, associations, and organisations are looking more carefully at the dimension of work place culture of physics. Relevant studies will be discussed in this section.

German anthropologist Agnes Senganata Münst (2009), for example, analysed the efficacy of gender in teacher-student-interactions in co-educative science and engineering courses at a technical university. Using participant observation, Münst looked at different situations in lectures and courses for undergraduate physicists and engineers. In a physics course she observed the spatial distribution of students and teacher in the classroom and the interactions that were supported or hindered by this spatial distribution during some weeks. All female students used to sit in the front rows while most of the male students used to sit in the back rows of the classroom. Most of the time, the teacher stood not in front of the class, but next to the front rows. From this position he could easily make eye contact to the male students in the back, but had to turn if he wanted to address the female students. This spatial distribution supported that the teacher was always looking at and talking to the male students. Only if he did not get satisfying answers he turned around and addressed the mostly female students in the front rows. Münst showed in detail how subtle micro-inequities initiate, in a world of formal equality, immense differences in the way female and male students were noticed, addressed and confirmed to possess the necessary professional qualification (Münst, 2009).

The cultural turn in humanities and social sciences led to a variety of understandings of the term culture, covering different aspects of investigation. Media studies look at the gendered image of physics in society. Erlemann (2009) in her analysis of the representations of physics in German print media showed that even progressive magazines fail to offer a desirable job description because they fail to picture women physicists simultaneously as successful researchers and likeable females. Anthropological and ethnomethodological studies described research and technology as part of a cultural framework and observed how research environments negotiate their own sub-cultural values, meanings, and practices. Traweek (1988) in her study 'Beamtimes and Lifetimes' noted how scientists in high energy physics construct gender in male tales told during a life in physics. Knorr-Cetina (1999: 232-233) compared gender in the laboratories in molecular biology and high energy physics, and noticed that physicists (with the exception of Italians) exhibited a kind of "mono-gender" that is closer to masculinity than to femininity. Other scholars analysed the historical presentation of physics as a male genealogy or a 'male master–male disciple' relationship that decided which gender may or may not continue the cultural heritage (e.g., Lucht, 2004; Traweek, 1988: 77).

Several studies point out the appeal of doing physics but also the blatant and subtle discriminatory structures female physicists experienced in their professional training and work at universities (e.g., Lucht, 2004; Lundborg/Schönning, 2007). Hasse and her research team on 'Understanding Puzzles in the Gendered Map of Europe' looked in detail at both, the diversity of national cultures and gender difference in university work place cultures of physicists in Denmark, Estonia, Finland, Italy, and Poland, to understand the huge differences in numbers of female physics professors ranging from 3% (in Denmark) to 23% (in Italy). One factor the group identified for supporting or hindering women's careers in physics was the different understanding of creativity in national work place cultures,

attributing creativity in physics to individual or teamwork achievements or seeing it as an undesirable attribute (Hasse/Trentemøller, 2008; Hasse et al., 2008). Keeping in mind that physics is an almost male and white activity (e.g., Nelson, 2002), US-American feminist science studies scholars who examined the culture of physics noted the increasing entanglement of science with gender, race, class, and sexuality. Ong (2005), for example, examined the strategies of ten minority female physics students trying to manage challenges to their competence and membership that were caused by racial and gender prejudices in their local physics communities. Although some important preliminary work has been done (e.g., Jordan, 2006), intersectional investigations on physics are underdeveloped.

Historians of science get information on local scientific cultures by looking at women in science (and vice versa). Gould (1998) studied partnerships and collaborations between male and female physicists to make female researchers visible. She examined the work place atmosphere for seven female researchers at the Cavendish laboratory at Cambridge University and characterised the culture of university physics by collaboration, integration, and partnership (Gould, 1997). Rentetzi (2004) in her work on the Institute for Radium Research in Vienna stressed the importance of the work place culture and identified two crucial causes supporting women at this institute. The social democratic party's concepts of health care and education supported medical research on radium therapy as well as girls and women in higher education and professional training. Moreover, Hans Pettersson's research group on artificial atomic decays practised an encouraging, team oriented experimental style at the institute. Wertheim described the style of physics as a religious activity with a conspired club of priests throughout centuries and showed that the priestly culture predominates in contemporary physics when research projects in particle physics are advertised by employing a quasi-religious rhetoric. This atmosphere can be a powerful gendered barrier to women (Rolin, 2008: 1115-1117; Wertheim, 1995).

In summary, these historical, sociological, and anthropological studies on physics in Western cultures as well as on physics as a work place culture highlighted different aspects of physics' gendered cultures. In shifting the focus from the "problem of women in physics" to the "problem of physics with women", the research gave insight into the external and internal processes that created a welcoming or chilly climate for women and minorities at the work place and that supported or hindered their careers in physics. Therefore, the empirical outcomes of these studies on work place cultures in physics have a political interest and are useful to develop programmes to overcome unbalance and injustice in physics. At the same time this research, in my view, is limited in such a way that while examining gender in the social and cultural context of physics, it does not reflect on gender in the knowledge production and the consolidated knowledge in physics.

Knowledge Production in Physics

The dimension of analysis on the knowledge production in physics consists of research questions on the entanglement of gender and the body of consolidated knowledge in physics. A few historical, linguistic, philosophical, and theoretical works already exist and will be discussed in this section.

Studies on the knowledge production of physics shifted the image of physics from an area of eternal truth and solid knowledge to an area of human endeavour and processes of solidification. Gender researchers

explored how physics constitutes images of gender, how gender feeds into the description of the material world, and how epistemological concepts relate to gender. Materiality is one of the epistemological concepts that have recently gained attention in gender research. Karen Barad's theoretical work, for example, explicitly relates to materiality in physics (1998; 2001; 2007). Barad, a theoretical physicist and professor of feminist studies at University of California, Santa Cruz, explored 'how matter comes to matter' (Barad, 2001), through an analysis of piezoelectric processes that occur in ultrasound measurement instruments when used in foetus examinations. She developed a feminist theory of 'agential realism', an understanding of reality that comes into being by activities of agents, to overcome the dichotomy between discovery/subject/culture (epistemology) and being/object/matter (ontology) and lead to 'epistem-onto-logy'. Barad's theory builds upon Judith Butler's theory of performativity (Butler, 1993) as well as other US-American theoretical discourses. For Barad post-structuralist feminist theories have a one-sided focus on the cultural representations of objects and too little on the objects themselves. In Haraway's sense (Haraway, 1991), however, bodies in material sciences are understood as resistant and actively performing entities that humans can interact with in material-semiotic nodes. Barad uses this concept and discusses 'intra-actions' in order to show that research subjects and research objects come into being through this process. In this approach, she used Niels Bohr's physical-philosophical interpretation of quantum mechanics (Bohr, 1957). In Bohr's 'Copenhagen Interpretation' the unusual performance of small particles compared to macrophysics can be explicated in that the observed characteristics only come into being during the process of observation. Barad drew parallels to the performativity of the discourse practice as it pertained to post-structural feminist theories. Similar to discourse practices, physical measurement practices created materiality. Feminist theories should consider this 'intra-action' of researchers and bodies, and the production of materiality via discourses and performativity (Barad, 2007).

While scholars in mainstream social studies of science explored the social constructions of scientific realities and the production of knowledge in scientific laboratories without stressing a gender analysis (Erlemann, 2009: 94; Rose 1997: 27), connections between gender and the consolidated knowledge of science were successfully studied in gender research (although mostly in biology, psychology, medicine, and anthropology). In her analytical level of gender in the results of science and engineering, Schiebinger (2008: 14-21) focused on analysing how gendered practices and ideologies have structured scientific knowledge. Moreover, she underlines that frameworks of gender analysis in physics and chemistry should be developed. Keller (1995: 86) sub-divided research on gender and science in a narrower sense into studies of scientific constructions of sexual difference (science of gender) and studies of the uses of gender in scientific constructions of subjects and objects (gender in science). Having scholars from feminist theory, history of science, and natural science (mostly biologists) in mind, Keller stressed gender in science as a trading zone, trading multidisciplinary studies of gender, language, and culture. Bauer (2006: 169) enhanced Keller's classification by adding a perspective of "feminist epistemologies". He argued that feminists discussed epistemological issues, such as objectivity and materiality, which in their fundamental scope exceeded the perspective of gender in science.

In all there are only a few researchers who focused their gender analyses on the

dimensions of knowledge production in physics. Some analysed "physics of gender" and studied how the representation of the concepts in physics advanced ideas about men and women, about masculinity and femininity. For example, around the year 1900 scientists inferred from laws of thermodynamics that women would only follow their 'nature' and give birth to healthy children, if they avoided intellectual work and did not waste their energy by working as professors in academia. Thus, Max Planck and others used the concept of energy conservation of thermodynamics to prevent the rivalry between men and women in academia (Heinsohn, 2000). Similarly, the natural philosopher Johann Wilhelm Ritter used concepts of indifference and polarisation of 18th century research on magnetism to explain woman's 'natural' longing for conception and pregnancy (Holland, 2006).

Other researchers analysed "gender in physics" by looking at the history or language of physics. Some gender studies scholars took the historical analyses of the connections between physics and society as a starting point to add gender to the picture. For example, when Wolff (1978) published his history of the concept of impetus and described this scholastic theory of motion in analogy to economical concepts of medieval time, Scheich (1985; 1993) criticized this work because of the lack of gender analysis. She argued that the disregard for female reproduction work in the economical theory of that time is reflected in the scholastic theories of the impetus; and this erasure is continued in Newton's laws of motion. Shapin and Schaffer (1985) addressed the question of how Boyle's epistemological assumptions on experiments in general, and on the vacuum in particular, were influenced by his social and political thoughts in times of British civil war. Their work was highly celebrated for showing the influence of social currents on physical chemistry, although their analysis ignored gender questions and that Boyle actively engaged in the gender debate of his time. Potter, in responding to Marie Boas Hall (Boas, 1958) and Rose-Mary Sargent (1995), worked on that question and argued that English notions of class and gender of the 17th century influenced Boyle's choice of a corpuscular or mechanical interpretation of the experiments with the air-pump, which were inscribed into Boyle's law of gases (Berner, 2004: 99-102; Potter, 1988; 2001). Potter's interpretation, however, was discussed within the feminist discourse of philosophers of science as only possible but not truly evident (e.g., Rolin, 1999: 512; Sargent, 2004). Not only do historical case studies analyse scientific knowledge from a gendered perspective, other writings discuss the gendered language of today's physics, especially in the nuclear arms race and the military (e.g., Cohn, 1987; 2001; Easlea 1983), or in prestigious subfields such as high energy physics, where (hetero) sexuality is inscribed in the devices and the standard model of elementary particles (e.g., Götschel, 2006; Traweek, 1992), while notions of patriarchal hierarchy exist in the understanding of scientific theories and the conceptualisation of particle physics (Rübsamen, 1983; Whitten, 1996). Moreover, gender attributions become very apparent in popularized physics, e. g. when the proton 'Protoni' is described as a 'poor lonesome cowboy' (Gisler, 2001).

Further, researchers considered epistemological reflections on the attributes of experimentally produced 'nature' from a gender point of view. They work in the area of "feminist epistemology of physics". Objectivity, as discussed in the US-American feminist philosophical discourse, can be understood as socially negotiated knowledge, as a reflection of cultural values that need reworking, or as partial and situated knowledge (Longino, 1990; Harding, 1991; Haraway, 1991: 183-

202). Materiality is another concept that recently has undergone an epistemological reflection in the USA feminist theorists' discourse (Alaimo/Hekman, 2008) which opens up possibilities to connect physics with theories of performativity, as done by Barad (2007) (see above).

In summary, gender research on the knowledge production in physics, while in my opinion very exciting and fascinating, is an underdeveloped area of research. Early attempts to analyse the physics of gender, gender in physics, and feminist epistemologies in physics often referred to standpoint theories and history of ideas, whereas more recent analyses in many cases correspond to cultural studies and post-structuralist theories. The analysis of social influence on the body of consolidated knowledge in science, although being on the agenda since the rediscovery of Ludwik Fleck's work (Fleck 1979), seems to be the most difficult and challenging area for both science studies scholars and gender studies scholars. Definitely more research needs to be done and these research results certainly need to be discussed, criticised, and defended by an interdisciplinary research community. Furthermore, actor-network-theory, the most successful theory in the social studies of science, explaining the effects of successful translations of actors, forces, and interests, has to my knowledge not yet been applied to gender and physics, but might be a fruitful way to entangle human actors, work place cultures, and knowledge production in gender and physics research.

Conclusion

The research on gender and physics is multifarious and can be systematised into three dimensions of analysis focused on epistemological interests and the objects: Human Actors, Work place Cultures, and Knowledge Production. I have illustrated each of these dimensions with one selected example in greater detail and an overview of further results of gender and physics research. World-wide, numerous studies have emerged that focused on human actors in physics. Analyses of physics' work place cultures are a promising research interest in gender and physics studies because they shifted the focus from women to physics. In contrast, gender research on the knowledge production in physics is quite rare. All in all, many challenging questions have not yet been examined in feminist and gender physics research. Too little is known, for example, about the conditions and contexts that induce innovative ideas and their integration into the knowledge system of physics, and about the role that cultural contexts and their associated gender systems play in this process. Furthermore, gender analyses should be tightly linked with other categories of social inequality and cultural differentiation, such as class, race, ethnicity, and sexuality.

Because expertise in physics, science studies, and gender studies is needed to address these research questions in an adequate way, the exchange of ideas and expertise between science studies scholars and gender researchers seems to be the most promising approach to analyse the entanglement of gender and physics, particularly the gendered, consolidated knowledge of physics. For over a decade, Keller (1995) has called for establishing trading zones for multidisciplinary exchange of research on gender and physics between gender studies scholars and science studies academics. This suggestion could bring together the different research interests and expertise in the three outlined dimensions of analysis and beyond. Moreover, it could overcome some of the limitations and blind spots of today's research on gender and physics. How this might be put into practice, however, remains to be seen.

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