The Social and Epistemic Organization of Scientific Work

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Science is work, and viewing science as a form of work demystifies it, eclipsing the quest for timeless truth with more mundane efforts to secure resources, conduct research, construct arguments, open (and protect) spheres of inquiry, and produce evidence convincing enough to pass through peer review into print. How scientific work is organized matters for science as knowledge and practice, shaping what is learned and how work is done. The work of scientists is organized into an overlapping and intersecting array of social and institutional arrangements. Scientists collaborate with one another and with citizens, students, technicians, practitioners, and other professionals in organizational settings that include disciplines, specialties, and research areas; for-profit, government, and nonprofit sectors; universities and departments; institutes and centers; invisible colleges and thought collectives; paradigms and epistemic cultures; research schools, groups, and teams; collaborations, laboratories, and collaboratories; social networks and social movements; boundary organizations, synthesis centers, and countless hybrids and variants of these. Demystifying scientific work and inquiring into its organizational form bring into focus three broad themes that have both analytic and normative aspects: First, how is scientific work organized at various scales, ranging from the institutional to the microsocial? Such questions have driven scholarship in science studies and cognate fields, and have practical and normative implications for science policy and management. Second, how do epistemic and social processes interact to form (and re-form) disciplines and specialties? The creation, diffusion, and application of scientific knowledge are causes and consequences of the organization of scientific work, and the alignment of science to social purposes that is built into scientific organizations shapes what research is done and what remains undone. Finally, the evolving epistemic and social patterns of scientific work—in particular, the essential ambiguity in the ever-tightening coupling of scientific inquiry to societal purposes—entail principles of scientific governance that bring power in all its forms to bear on the institution of science. Asking how science and its organization are co-produced has yielded sharp and enduring insights into the organization and dynamics of science.

The social organization of science has been a core concern of science studies *avant la lettre* for nearly a century (e.g., Fleck [1935] 1981; Merton [1938] 1970; Weber [1918] 1948) and continues to attract intense scholarly activity. This line of inquiry has generated various ways of understanding the interaction between science and its organization, such as epistemic cultures (Knorr Cetina 1999) and co-production (Jasanoff 2004), and extends beyond STS into such fields as the history of science, organizational behavior, network science, economics, sociology, informatics, and the nascent Science of Team Science ("the other STS": Hall et al. 2012; Paletz, Smith-Doerr, and Vardi 2011). This chapter engages with this vibrant and varied literature, describing current ideas about the social organization of science, how they have evolved, and what they mean for science, for society, and for social studies of science.

New ideas for organizing science are as old as organized science itself, and three venerable but still generative ideas orient our discussion. First, seventeenth-century utopias such as the New Atlantis, the City of the Sun, and Christianopolis prominently positioned imaginative new scientific organizations in their imagined landscapes, sometimes at the center and open to societal engagement, other times near the periphery and separate from quotidian affairs. The Accademia dei Lincei, an organization founded by Federico Cesi in 1603 and still active today, offered a grand humanistic vision of scientific collaboration guided by principles of justice and righteousness that would cross national and disciplinary lines to work for the greater good of humanity. The Future Earth initiative (launched in 2012), taking form under the aegis of the International Council for Science (ICSU), is a successor to this grand vision of science organized on a global scale for the benefit of all. The organization of scientific work and its place in the social order have been under negotiation and construction for centuries, and there is every reason to expect this to continue.

Weber's lecture on "Science as a Vocation," delivered at the University of Munich in 1918, offers a second point of orientation. At that watershed moment science existed simultaneously as a vocation or calling and in an emergent form that was more bureaucratic and less enchanted, conducted in alienating "state capitalist institutes ... of medicine or natural science" whose members endured "quasi-proletarian existences" (Weber 1948, 131). Looking backward, Weber saw the scientist of seventeenth-century London pursuing a gentleman's avocation alone or alongside his nearly invisible technicians (Shapin 1994). Looking forward, he saw the outlines of academic capitalism and the economic dependence of science that have created a marketplace where scientists sell their ideas and services at some cost to their calling and commitment (Hackett 1990; Mirowski 2011; Slaughter and Rhoads 2004; Stephan 2012).

The third reference point is the exponential growth and concomitant differentiation of science, first noticed by Price, which caused a dramatic rise in scientific collaboration that "has been increasing steadily and ever more rapidly since the beginning of the [twentieth] century," causing "one of the most violent transitions that can be measured in recent trends of scientific manpower and literature" (Price 1963, 77–79). This powerful transformation of scientific work has been driven by a sharp rise in public investment in research and a concomitant rising expectation that the investment will yield greater health, prosperity, and security.

Underlying these landmark reflections on the organization of science are three intertwined dynamics, and we will discuss each in turn. The first is *aggregation*, which ranges from the lone investigator to large, bureaucratic research enterprises. The second is *specialization*, the social and material processes that initiate and shape new areas of research. The third is interdisciplinary integration, or *synthesis*, which counterbalances specialization through the creative recombination of data, expertise, and ideas, often with practical applications in view. We close by discussing how aspects of the organization of science influence its purposes, politics, and place in society, and by offering ideas about the social organization of science in the future and the research challenges these will offer STS scholars.

Aggregation

The aggregation of science has been studied at scales ranging from the community or institution of science through disciplines and specialties to small groups, teams, laboratories, and individuals. Fleck and Merton first showed how groups of various sizes shape the organization of knowledge production. Fleck (1981, 1986) argues that science advances through the activities of "thought collectives": small, intensely interacting research groups that through persistent intellectual and emotional exchange develop a distinctive cognitive framework (or "thought style") that guides problem choice, evaluative standards, and literary styles (1981, 39, 99, 106). Shifting social relationships within the collective correlate with changes in research perspective and working style (1986, 74–75). In *Science, Technology and Society in Seventeenth Century England*, Merton maintains that the development of a sufficiently sizeable network of talented researchers, combined with cultural and material factors, provided the social matrix necessary for the development of the Royal Society of London and the rise of science as an independent social institution (1938, 78).

About twenty-five years later, Kuhn built on these ideas in *The Structure of Scientific Revolutions* (1962), proposing that the incremental growth of scientific knowledge is complemented by occasional episodes of revolutionary change brought on by the accumulation of anomalies that defy accepted explanations. Recognition of the profoundly social and emotional process of revolutionary change in science sparked a revolution in science studies, unleashing a torrent of research. Kuhn's initial focus on "scientific communities" (1962) was replaced in the second edition (1970) by "scientific specialties" of up to several hundred people competing with one another for intellectual hegemony over a substantive area. Scholars now understood that the all-too-human competition for recognition and reward drove epistemic change in science. But only with the work of Fleck and Kuhn, and their concepts of "thought collectives" and "paradigms," did interaction between the organization of science and scientific knowledge become visible, revealing how organizational transformations affect knowledge production, and how cognitive innovations have social implications.

During the same decade, Hagstrom's *The Scientific Community* (1965) demonstrated the importance of small scientific groups by arguing that solidarity and conformity within the scientific community are principally grounded in social control produced through informal interpersonal exchanges that take place in local contexts, such as the corridors and offices of academic departments and laboratories. Allocation of scholarly recognition and moral reproach by peer groups motivate creative scientific work and suppress scientific misconduct. Such interactions make the institutional purposes of science salient for everyday scientific work; complementarily, the social control of science as an institution emerges from its exercise within smaller scientific groups and networks.

"Big science"—the science of big instruments, big groups, and big money—was first investigated in the 1960s (Price 1963; Weinberg 1961). The concept was initially applied to large-scale physics research (e.g., the Manhattan Project), and later to astronomy, space research, ecology, and molecular biology. The term has taken on a variety of meanings (Capshew and Rader 1992), but common features include centralization around large and expensive instruments, industrialization, multidisciplinary collaboration, institutionalization, science-government relations, and internationalization. Such changes reflected the scaling-up of various processes during the modern era, and wonder at the scope of these transformations was tempered by concern about the diseases of "adminstratitis, moneyitis, and journalitis" (Weinberg 1961) and the decline of the intellectual mavericks (Price 1963). Debates about the appropriate scale for science continue (Vermeulen, Parker, and Penders 2010; Westfall 2003). The study of exponential growth in science stimulated other quantitative metrics, turning Price (a physicist and historian of science) into an acclaimed information scientist and a founder of bibliometrics (Elkana et al. 1978; Garfield 1984).

Price's quantitative approach, blended with a sociological reading of Kuhn's work and network analytic methods, sparked the first attempts to link scientific groups with changes in the content of scientific ideas. Ben-David and Collins (1966) showed how social relations among small groups of collaborators aided in the development of psychology, while Crane (1969, 1972) contended that science is mainly performed and evaluated within "invisible colleges"—small, dense, informal research networks. Building upon these foundations, Mullins (1972, 1973) and Griffith and Mullins (1972) proposed that "coherent groups"—small, highly emotive, intensely interacting research groups—are the primary drivers of scientific change, and seed the larger invisible colleges that develop around them. Together, these studies formed a specialty within science studies that focused on the development of scientific specialties (e.g., Chubin 1976; Cole and Zuckerman 1975; Edge and Mulkay 1976; Law 1976). Studies of scientific/intellectual movements (Frickel and Gross 2005) continue this tradition by joining the small-group dynamics that form the energetic kernel of scientific social movements to the large-scale dynamics of change.

Studies of laboratories first received systematic ethnographic study in Bruno Latour and Steve Woolgar's *Laboratory Life* (1979).[1] Conceptualizing lab scientists as members of tribes, they explored how researchers transform experiments into publications, arguing that technical facts are constructed rather than merely communicated. Focused on "science in the making" (Latour 1987), lab studies became a central concern of STS: scholars entered labs to explore their knowledge-producing practices. Traweek (1988), for instance, compared high-energy physics communities, while Knorr Cetina (1999) explored the epistemic cultures of molecular biology and particle physics, detailing scientists' collaborative patterns and ways of justifying knowledge claims. Lab studies nourished development of STS (Doing 2008), but the community's immersion in labs also made it difficult to see how science and technology interact with the world outside laboratory walls. Exceptions include studies of how institutional isomorphism brings business and professional standards and practices into the university (Hackett 1990), how articulation work aligns laboratory strategies and practices with the demands and interests of the wider world (Fujimura 1996), how asymmetrical convergence causes academic labs to resemble their for-profit counterparts (Vallas and Kleinman 2008), and how knowledge and social order are co-produced in practice (Jasanoff 2004).

Building on "big science" studies, the turn of the millennium witnessed increasing interest in scientific collaboration at scales ranging from groups through international research networks. Such collaborations may involve citizens, practitioners, and other professionals and may reach beyond scientific aims to societal purposes. They may be informally organized or firmly institutionalized, and their membership and aspirations may extend across institutional or national boundaries. In such arrangements collaborators share expertise, credibility, and resources (Hackett 2005a; Maienschein 1993) and are drawn together by funding programs, political motivations, pressure for societal relevance or simply because collaboration is viewed as good in and of itself. Overall, collaboration is driven by a variety of purposes, and while collaborations in different specialties have different characteristics (Vermeulen, Parker, and Penders 2013), they are seldom truly global (Wagner 2008).

Collaboratories are arrangements of information and communication technologies (ICTs) that support collective data analysis, remote operation of instruments, and collaboration at a physical distance (Glasner 1996; Olson, Zimmerman, and Bos 2008; Wulf 1989). Collaboratories widen access to research resources, promote interdisciplinarity, and may bridge the world's crippling knowledge divides by building research capacity in the global south (ICSU/ISSC 2010).

Alongside aggregation, scholarship also demonstrates individualizing aspects of research. For instance, before the era of large-scale molecular biology Knorr Cetina (1999) argued that knowledge production in that field depends on individual exchange, in contrast to the integrated collaboration required in particle physics. Additionally, Shapin (1994, 2008) maintains that the personal virtues of individual researchers, such as trustworthiness and honor, were critical for the development of science as a social institution. Further, he contends that the radical uncertainties of contemporary science make this ever more the case today. Investigation of the interaction between the individual and the collective is encapsulated in the concept of "epistemic living spaces" (Felt 2009), which shows how the personal and the institutional are intertwined and shaped by broader epistemic, symbolic, and political forces.

STS is currently moving simultaneously toward analyses of the very small and the very large. At one extreme are studies of small group collaborations that ask how the social and physical environments of groups interact with their composition to shape scientific knowledge. This includes investigations of research groups (Hackett 2005b; Hampton and Parker 2011) and "collaborative circles" (Farrell 2001; McLaughlin 2008), coherent groups (Parker and Hackett 2012, 2014) and the emerging "Science of Team Science" (Hall et al. 2012; Stokols et al. 2008). At the other extreme, bibliometricians have mapped the entire scientific enterprise to uncover relations between disciplines and track the broader influence of articles, research centers, and policy decisions on science writ large. Such efforts originated in the 1970s (Small and Griffith 1974), underwent an unsettled period in the 1980s (Leydesdorff 1987), and have emerged as one of the most technically sophisticated communities studying science today (Boerner 2010; Leydesdorff and Rafols 2009).[2]

Studies of the growth and aggregation of scientific organizations provide knowledge useful for improving science policy and management. The Science of Team Science, for example, enthusiastically offers itself as an instrument for improving the efficacy of collaboration, while maps of science reveal hot and cold regions and survey territory fertile for investment and investigation.

Specialization

STS's analysis of aggregations small and large is set against the backdrop of the history of specialization of scientific knowledge, punctuated by episodes of recombination or integration. The scientific community is a patchwork of overlapping groups, networks, and communities of practice drawn together by shared identities, problems, and methods, and separated by cultural, historical, and epistemic fissures and fault lines. The emergence of disciplines contributed to processes of specialization—beginning with natural philosophy and ramifying into the research areas we know today—and discipline formation, recombination, and branching became focal concerns of the social history of science in the late 1970s (Clarke 1998; Sturdy 2011; Suárez-Díaz 2009).[3] However, studies of disciplines and specialties are written in a highly variable vocabulary that ranges across the map of science: paradigms, social worlds, epistemic cultures, thought styles and cultures, ways of knowing, styles of scientific reasoning, and many more.[4]

Disciplines, specialties, and research areas arise for several reasons: new research apparatus or techniques illuminate the previously unknowable (Bechtel 1986; Clarke 1998; Mulkay, Gilbert, and Woolgar 1975); scientific roles and occupations form at the intersection of established ones (Ben-David and Collins 1966; Frickel 2004); coherent networks arise around potentially generative questions or phenomena (Griffith and Mullins 1972; Powell et al. 2005); research captures the attention of influential interest groups (Clarke 1998; Frickel 2004; Lenoir 1997); new uses are found for new scientific knowledge (Schweber 2006; Shostak 2005). The cumulative effects of several factors often enable the institutionalization of a new field.

The development of fields and specialties typically follows a pattern (Chubin 1976; Collins 1998; De May 1992; Parker and Hackett 2012). Initially, researchers at several locations begin exploring similar problems without knowledge of each other's efforts, and publication is widely dispersed across different disciplinary journals. Through such publications researchers gradually become aware of their common interests. Dense channels of formal and informal communication arise among researchers, and these networks thicken to become the coherent groups and invisible colleges of the nascent research area (Crane 1969; Farrell 2001; Mullins 1972). Improved communication occasions scientific debate and consensus gradually emerges about problems, definitions, techniques, and findings. As it stabilizes the community develops a characteristic *thought style*: a shared cognitive framework characterized by common perspectives, evaluative standards, methods, techniques, and literary styles (Fleck 1981, 99; Hacking 2002; Rose-Greenland 2013). Thought styles are emotive and cognitive, activating "a certain mood" that facilitates "directed perception, with corresponding mental and objective assimilation of what has been so perceived" (Fleck 1981, 99). The thought style gradually enforces a social and cognitive way of doing and seeing, stabilizes meanings, and reinforces the thought structure. The community now perceives the world differently, resulting in potentially incommensurable understanding between those within and outside the new, semi-autonomous scientific domain (cf. Knorr Cetina 1999; Kuhn 1962).

Communication and intellectual growth are inseparable from material aspects of the scientific process. Disciplines are also constellations of practices, instruments, and materials that structure work and shape social networks and thought styles (Collins 1994; Latour 1987; Law and Hassard 1999). Machines, tools, technologies, protocols, and institutes, as well as buildings and journals, are fundamental components of disciplines and epistemic cultures (Fujimura and Chou 1994; Knorr Cetina 1999; Schoenberger 2001). Experimental systems (Rheinberger 1997), platforms (Keating and Cambrosio 2003), and ensembles of research technologies (Hackett et al. 2004) position epistemic things near the center of the research process. The social networks that form new research areas coexist and interact with genealogies of research systems that are manipulated to produce new scientific phenomena and enable the high-consensus, rapid discovery science (Collins 1998; Hackett 2011; Schroeder 2007). Importantly, all these require resources to construct, coupling science more tightly to the interests of the state and capital, and each is itself a resource that imposes social control, promotes competition, and produces stratification.

Once established, research communities are socially stratified and characterized by internal solidarity and external conflict and competition among groups within the field (Becher 1989; Bourdieu 1988). They become arenas of competing emotional and intellectual alliances (Gieryn 1999; Soreanu and Hudson 2008) or "strategic action fields" in which multiple groups compete for status and attention (Bourdieu 1988; Collins 1998; Fligstein and McAdam 2012). But conflict and competition are not the only motivations: the demands of the local social milieu, attempts to realize one's intellectual potential, and the biographical and existential meaning provided by scientific work also propel disciplines (Camic and Gross 2008; Parker and Hackett 2012, 2014; Swedberg 2011).

Disciplinary growth and development resemble social movements (Frickel and Gross 2005). Subgroups within the scientific community attempt to develop and win acceptance for research programs that challenge the current state of scientific knowledge or supplant established scientific techniques, often in the face of tremendous resistance from other scientists. Such movements can succeed when they mobilize key material and emotional resources and high-status intellectuals and recruitment centers, and when they frame their research in ways that resonate with others in the field. After the intellectual beachhead has formed, the movement's ideas become accepted and gradually institutionalized into professional associations, conferences, journals, and (rarely) a new discipline (De May 1992).

Once established, disciplines become structured in ways that influence knowledge work. These include the types of resources needed to conduct research (Frickel and Gross 2005), the power of peer review (Crane 1972; Csíkszentmihályi 1999), and each discipline's relative degree of "attention space"—the number of creative contributions that can be accommodated in journals, conferences, and elsewhere (Collins 1998). Each factor shapes the social organization of scientific work. Consider, for instance, field-level consensus, or the level of agreement among researchers in a field about research questions, methods, and meaningful scientific contributions. Members of high-consensus fields enjoy greater funding, greater autonomy, and more collaboration (Beyer and Lodahl 1976; Fox 2008; Pfeffer and Langton 1993). In low-consensus fields systems for communicating scientific methods and results are more idiosyncratic, research coordination and control units are smaller and less powerful, and considerable theoretical pluralism exists (Fuchs 1992; Whitley 2001). The organization of research in scientific fields, structured by the investment and distribution of resources, shapes scientific knowledge and practice.

Integration

Disciplines and specialties accumulate knowledge by focusing research on specific topics addressed in characteristic ways that meet shared standards of evidence and closure (Jacobs 2014; Jacobs and Frickel 2009). Simultaneously, however, the narrowness of their subjects and methods, and the fact that many intellectual problems fall between or beyond research areas, mean that disciplinary horizons limit scientific advancement and the use of science to solve applied problems (Kostoff 2002). The increased burden of specialization is offset by further narrowing expertise, which limits one's ability to innovate through recombination (Jones 2009). Uneasiness about differentiation and the loss of unity in science can be traced back decades (Weingart 2010). As "researchers tend to work *on* problems, not *in* disciplines" (Klein 2000, 13), they mobilize elements derived from multiple styles, disciplines, or cultures of research (Radick 2000), and collect novel ideas that shape inquiry, collaboration, and the organization of communities (Barry and Born 2013; Strathern 2006).

Intellectual fragmentation stimulates efforts to re-integrate knowledge to produce holistic explanations, resulting in varieties of collaboration that extend beyond disciplinary borders (e.g., multidisciplinarity, interdisciplinarity, transdisciplinarity). These different modes of integration organize inquiry across the fault lines of scientific work and communities through methodological borrowing, theoretical enrichment, and convergent problem solving (Klein 1996). At the low end of integration, multidisciplinary collaboration draws methods, ideas, and theory from disparate academic disciplines and fits them together in much the same way that tiles form a mosaic: the tiles and their individual meanings remain identifiable parts of a new composite (Huutoniemi et al. 2010). Multidisciplinarity is thus additive rather than integrative: the disciplines and disciplinary frameworks remain unaltered and the relationships among disciplines are not well defined (Klein 2010). Interdisciplinary research, in contrast, achieves a qualitatively higher level of integration that dissolves the coherence of disciplines—the tiles are disintegrated and their constituent elements reconstituted into a coherent new whole. Integrative in process and outcome, interdisciplinarity is an epistemic accomplishment that reaches across the hierarchic division of disciplines to meet the challenges posed by complex questions and problems (Klein 2010). Transdisciplinarity, the most unusual and ambitious of the three collaborative varieties, *transcends* boundaries separating disciplines and professions (Felt et al. 2013; Nowotny, Scott, and Gibbons 2001), reaching into other sectors and communities to fashion coherent solutions and explanations from a diversity of expertise, evidence, and epistemic practices. Critical, transgressive, and synthetic, transdisciplinarity is "the contemporary version of the historical quest for systematic integration of knowledge" (Klein 2010, 24).

Beginning in the mid-1990s, multi-, inter- and transdisciplinary research has been accompanied by scientific synthesis, a new form of scientific collaboration that integrates disparate theories, methods, and data across disciplines, specialties, professions, and scales to produce explanations of greater generality or completeness (Carpenter et al. 2009; Rodrigo et al. 2013). Synthesis happens when theories, concepts, methods, and data are imported from quite different sources—within science and outside—in collaborations often catalyzed by an urgent problem or compelling intellectual challenge.

Synthesis produces emergent knowledge that extends beyond any one discipline, dataset, or method. It occurs both within and across disciplines, specialties, and sectors, and so differs in substance and scope from interdisciplinary and transdisciplinary research.

Specifically constructed for the purpose, synthesis centers (http://synthesis-consortium.org) convene small, intensely interacting working groups of about five to fifteen scientists, policy makers, and practitioners with complementary expertise and data to focus for several days on research problems contributing to fundamental understanding and practical problem solving (Hackett et al. 2008; Hampton and Parker 2011). Synthesis groups gather experts in different disciplines and professions and isolate them for a strictly delimited period of time. The emotional energy and social solidarity of the working group allow collaborators to overcome initial resistance to intersectoral or interdisciplinary collaboration, which, in turn, facilitates rising levels of trust and instrumental intimacy, productive alternation between creative and critical modes of scientific practice, and group flow (Hackett and Parker 2016; forthcoming). Consequently, synthesis groups engage in a highly creative and productive intellectual process, accomplishing in several days what takes other groups months or even years to achieve (Hackett et al. 2008). Synthesis offsets the negative effects of hyperspecialization, leverages massive and diverse data, and increases chances of serendipitous discovery and transformative science. As such, it is vital for a future in which increasingly specialized sciences face intellectual questions and real-world problems that demand rapid application of ideas and evidence drawn from a wide range of sciences and other bodies of expertise.

The Purposes and Politics of Scientific Organization

Characterizing science as work and examining it carefully exposes its political implications and social inequalities. Just as politics arises in the social and epistemic tensions between specialization and integration, the politics of scientific organization become apparent in discussions about the purpose of science and its connection to other sectors in society, especially government and industry. Tensions also arise between the scientific collective and the individual scientist in such matters as the management of research, access to instruments and materials, accountability, job satisfaction, and stratification.

Fifty years ago the distinction between basic and applied research mattered a lot, with nonacademic scientists working on different problems and in different ways than their counterparts in academe (Mulkay 1977; Pelz and Andrews 1966). But in recent years new conceptualizations have arisen, grounded in new understandings of the social purposes of science. Underlying this changed relationship is a transformation from an *industrial* to a *postindustrial society*, as already suggested by Bell (1973) and Drucker (1969), which ushered in a knowledge society founded upon science and technology rather than industry. While Bell and Drucker offer similar analyses of this transformation, they envision quite different implications for the position of science (de Wilde 2001). Bell imagines a privileged place for theoretical knowledge and knowledge institutions, while Drucker predicts the industrialization and commoditization of knowledge. Seen from the vantage point of 2015, Bell's vision seems as idealistic as the utopians described in the chapter introduction, while Drucker's *realpolitik* echoes Weber's prescient warning.

More recently, those who maintain that there has been a transformation from *mode 1* to *mode 2 science* sense the emergence of a new form of knowledge production that displaces disciplinary and fundamental knowledge practices with a more reflexive, transdisciplinary, and heterogeneous "knowledge production" situated in the context of application (Gibbons et al. 1994). Accordingly, the authors identify and perhaps advocate the reform of established institutions, disciplines, practices, and policies. A later book (Nowotny, Scott, and Gibbons 2001) argues that increasing societal complexity, uncertainty, and reflexivity require that science become more thoroughly embedded in society to produce "socially robust knowledge." Similarly, Funtowicz and Ravetz (1993) identify a transformation from *normal* to *post-normal science* that arises in the context of growing uncertainty—when uncertainty becomes fundamental and risks are high, knowledge practices deviate from Kuhn's "normal science." Post-normal science blends scientific methods and principles of conduct with values and practices drawn from outside the scientific community, creating a more pluralistic form of inquiry.[5]

The rise of post-normal science has stimulated collaboration between academic science and private industry, which, in turn, has elicited a vibrant body of theorizing and empirical research. Growing emphasis on the commercialization of public-sector research and development has encouraged universities to enter into cooperative agreements with industry to transfer and develop technologies with commercial potential (Owen-Smith and Powell 2003). As such, the *triple-helix theory* signals an organizational change from separated domains in society to the entanglement of the domains of science, government, and industry (Leydesdorff and Etzkowitz 2001) and can be read as a recipe for innovation in the organization and outcomes of science. These new views on the relation between science and society are also accompanied by discussions about for-profit science and public-private partnerships, and new reflections, theories, and policies on science and its role in society (which at the time of this writing is called "responsible research and innovation"; see Stilgoe and Guston, chapter 29 this volume).

Boundary organizations—formal institutions that mediate interactions between the science and policy communities, bridging their diverse purposes, incongruent values, and mutual incomprehension—are an increasingly common means of linking scientific work to societal purposes (Guston 1999; Parker and Crona 2012). In a boundary organization, researchers, practitioners, and policy makers, often enabled by professional facilitators, use boundary objects to motivate, coordinate, guide, and reward collaboration while discouraging partisanship and imbalanced influence.

Theories of boundary organizations emerged from pathbreaking work on boundary objects and boundary work (Gieryn 1999; Star and Griesemer 1989), and were originally developed in a limited array of distinctive settings where it was generally assumed that science and policy communities were clearly delineated and had equivalent ability to exert power over the organization. Boundary organization theory also assumes that the organization can reconcile conflicting demands and achieve lasting stability between science and policy (Cash 2001; Guston 1999). Boundary organization theory was later modified to account for boundary management in more complex institutional environments wherein the organization serves multiple stakeholders with different levels of power whose competing demands incorporate scientific, political, and industrial agendas. This perspective allows for more realistic analyses of boundary management in complex social environments (e.g., Crona and Parker 2011; Parker and Crona 2012) and has been particularly influential for understanding the use of boundary organizations to promote environmental sustainability (e.g., Boezeman, Vink, and Leroy 2013; von Heland, Crona, and Fidelman 2014).

The role of government in directing scientific work is seen clearly in the rise of strategic research programs and priorities, as has recently been occurring in the form of "grand challenge" campaigns that direct scientific inquiry and hold it accountable to societal purposes (Calvert 2013; Rip 1998).[6] In the 2000s, grand challenges became "a tool for mobilizing an international community of scientists towards predefined global goals with socio-political as well as technical dimensions" (Brooks et al. 2009, 9). For example, following the Gates Foundation (2003) initiative Grand Challenges in Global Health, 400 prominent researchers and politicians stated in the Lund Declaration (2009) that "European research must focus on the Grand Challenges of our time moving beyond current rigid thematic approaches" (1). Today there are grand challenges in many sectors, created either top-down or in public consultations, directing us toward certain futures and away from others (Calvert 2013).

Grand challenges and similar large-scale, targeted research initiatives often require scientists to organize in complementary ways. For instance, the international ATLAS detector at CERN involves about 3,000 researchers (http://www.atlas.cern), while the Laser Interferometer Gravitational Wave Observatory (LIGO) and the U.S. National Ecological Observatory Network (NEON) each cost nearly $500 million to construct. Such massive instrument-centered projects structure the research agenda and commitments of scientists and funding agencies for decades. They also entail demanding reviews before construction and for the many years of active research. The recent downsizing of the $433 million U.S. National Ecological Observatory Network is an example of what happens when large-scale science outgrows decision makers' willingness to pay (Mervis 2015).

Most prominently, these big science initiatives have contributed to the integration of management practices in research: science has become project work. Rooted in large-scale, government-driven scientific efforts, such as the Manhattan Project and the Apollo space program, project design and management developed in fields of construction and engineering during the 1960s (Cicmil and Hodgson 2006; Hodgson 2004; Lock 2003). As part of the New Public Management (Boston et al. 1996; Ferlie et al. 1996), the 1990s saw the project mode expanding across industries and other sectors in a process aptly described as the "projectification of society" (Midler 1995).

Nowadays collaborations and individual research are also predominantly project work, from national and European research programs to the work of Ph.D. students (Torka 2009; Vermeulen 2009). The project format determines the structure of the research process, for example, through clear timeframes and preset deliverables that often go against the grain of the uncertainty and openness of knowledge creation processes. Project funding requires a predefined proposal for research that outlines the goals and outcomes, the research process and its schedule—including a clear beginning and end, as well as participants and their responsibilities.

While this pattern of organization makes research more legible to outsiders and more accountable through audits and evaluations, it also contributes to the bureaucratization of research and its associated red tape (Power 1997). For instance, the U.S. National Science Foundation supports the construction of large-scale research instrumentation through the Major Research Equipment and Facilities Construction account that imposes strong reporting requirements and places enduring demands on budgets to support research that uses the newly developed instrument. First applied to such major research projects, the culture of evaluation has spread to performance-based, research-funding systems that establish resource levels for large-scale institutions (Butler 2010; Hicks 2012; Martin and Whitley 2010). Such evaluation systems employ peer review and/or academic output indicators, including some that measure societal impacts beyond the academic. These measures have become highly performative or reactive, yet at the same time influence resource distribution and other dimensions of stratification in science (Good et al. 2015; Rushforth and de Rijcke 2015).

Access to research resources—instruments and facilities, students and collaborators, and that most precious resource, time—is both cause and consequence of stratification in science. Science is stratified along many dimensions, including publication and citation rates, resources, credibility, and participation by women and members of certain ethnic groups (particularly at higher academic ranks or in more prestigious institutions; Cole and Cole 1973). For example, a small proportion of researchers are responsible for a disproportionate share of scientific publications, and a relatively small pool of articles receives a disproportionate share of citations (Garfield 2006; Lotka 1926; Price 1986). A small number of influential researchers thus wield vastly disproportionate influences on their fields. And though their representation has improved in recent decades, women remain underrepresented in science (European Commission 2006; National Science Board 2008; see Fox, Whittington, and Linková, chapter 24 this volume). The same pattern holds true for non-Western scientists, particularly among scientific elites. Across disciplines between 40 percent and 90 percent of the world's most highly cited scientists live in the United States and Western Europe (Basu 2006; Parker, Vermeulen, and Penders 2010). STS scholarship is similarly skewed, and only in the past ten years has a truly global STS community begun to emerge as conferences are held in non-Western countries and new regional STS journals are established.

The professional expectations and organizational environments of university faculty influence their job satisfaction and dissatisfaction (self-doubt and anxiety) (Hermanowicz 1998). Different tiers within the university system (high, middle, and low) constitute different academic "social worlds" with characteristic norms regarding performance, and which provide differential access to the resources needed to meet them. Professional expectations interact with these local resource availabilities to shape scientists' job satisfaction. Middle-tier researchers experience the greatest levels of job satisfaction because their performative standards are flexible and they have ample resources to meet them. Lower-tier researchers lack the resources to conduct meaningful scientific work and so experience less job satisfaction. Top-tier researchers have ample resources, but unrelenting pressure leads to dissatisfaction and perpetual self-doubt. The personal and emotive aspects of scientific work are shaped by the stratification system of science (Hermanowicz 2003).

Looking Forward

"... the future is not what it used to be ..."
(Laura Riding and Robert Graves, [1937] 2001, 170)

In the first edition of the STS handbook (Spiegel-Rösing and Price 1978, 93–148), Michael Mulkay arrived at Riding and Graves's view of the future of science by first reviewing the "sociology of the scientific research community" in a long chapter that began with the distinction between pure (basic) and applied research, outlined the normative structure of science and the social processes (rewards, exchange) that supported it, and sketched the dynamics of discipline and specialty formation. His view of the future is a valuable counterpoint to our own. Mulkay continued by observing that growth brings differentiation (specialization) and interdisciplinary collaboration, and the resulting networks (invisible colleges) offer communication channels, recognition, and coordination (once competition-driven secrecy eased). Differentiation and growth demand resources, creating dependence on government funding, accompanied by increasing expectations for rapid and certain societal benefits (tighter coupling of science to social purposes). Through this process pure research would be supplanted by applied research, Mulkay thought, leading him to close with some observations about its social characteristics.

Mulkay's chapter identifies the seeds of many transformative forces that are restructuring science today, most notably the diminishing desire of governments to fund research for its own sake (Schuster and Finkelstein 2006), accompanied by rising concern for its measurable societal benefits (construed narrowly in the United States as national health, wealth, and security). Today, however, the dichotomy between pure and applied research would be accompanied by "scare quotes" to signal distancing from such an unqualified distinction. To the extent one would today distinguish between investigator-initiated or curiosity-driven research and research that is specified and delimited by a patron, that distinction would be discussed as an essential ambiguity or tension that reflects a shifting compromise in the societal contract that organizes science.

Collaboration in varied forms is rampant (Parker, Vermeulen, and Penders 2010; Penders, Vermeulen, and Parker 2015; Wuchty, Jones, and Uzzi 2007), and specialization has sparked counterbalancing efforts at creative recombination. The capitalist spirit in science, first identified by Weber, is currently folded into a regime of academic capitalism (Hackett 1990), economization (Berman 2014), or neoliberalism (Mirowski 2011) that has all but obliterated the distinction between pure and applied research (and some would say that science was never pure anyway; [Shapin 2010]). Concern for the normative structure of science has long passed: counternorms (Mitroff 1974) and sociological ambivalence (Merton 1973) have given way to high-resolution studies of strategies for managing the essential tensions of science to productive and creative effect (Hackett 2005b; Hackett and Parker 2016; Lee, Walsh, and Wang 2015; Uzzi et al. 2013). Growth, differentiation, and the intellectual structure of science are today analyzed on a massive scale (Uzzi et al. 2013) and depicted in exquisite detail (Boerner 2010; Wyatt et al., chapter 3 this volume). Limited resources and scientists' dependence on them remain as challenging as ever, exacerbated by macroeconomic volatility that wracks whole economies and governments.

Several emerging trends will shape the social organization of science in the years ahead, and these changes pose challenges for science studies scholars. Technologies transform sciences, and ICTs are the most powerful and transformative technologies of our day and will be the foundation and accelerant for all of the others. ICT-mediated collaborative research, or "e-science," uses "the Internet as an underlying research technology or infrastructure" to alter research practices across various disciplines and knowledge domains (Meyer and Schroeder 2015, 4). Internet-mediated research is practiced at unprecedented scale, scope, and speed, and the practice is spreading rapidly. This explicit and formalized network-building process requires public rules of membership and thus represents a transition from the notion of the invisible college to that of a quite visible college or network of collaborators (Crane 1972; Price 1963). But distance matters (Olson and Olson 2000; Olson, Zimmerman, and Bos 2008), as do other differences: scientists within a building whose paths overlap are more likely to collaborate and secure funding (Kabo et al. 2014), whereas collaborations that span institutions incur transaction costs that impair performance (Cummings and Kiesler 2005). And intense, isolated, and enduring interaction fuels sociality, trust, and the escalating intimacy that promote scientific integration or synthesis (Hackett and Parker 2016, forthcoming; Parker and Hackett 2012). The paradox of ICT-mediated science and the challenges for STS scholars is to understand how to achieve the velocity and intensity that promotes excellent science while working at a distance with diverse collaborators. Perhaps the promise of ICTs is not their ability to do old things in new ways—that is, to host interpersonal collaborations and distal analysis and operation of instruments—but to do something quite new: to create "knowledge machines" and an emerging form of e-science that is qualitatively different from traditional modes of inquiry (Meyer and Schroeder 2015).

While transforming the microsocial processes of collaboration, ICT also enables global scientific collaboration at unprecedented reach and scale. The promise of such collaboration is reflected in the Future Earth initiative of the International Council for Science, for example, which aspires to construct a "global research platform" to enable collaboration among scientists and diverse societal partners to develop the knowledge necessary to initiate transformations toward sustainability and sustainable development (future-earth_10-year-vision_web.pdf). The global organization of research for humanitarian purposes is a noble pursuit with some 400 years of history (remember the Lincei), but the social organization of global research will be shaped by global concerns and considerations (competitiveness, sustainability, capacity building—or exploitation—of talent in developing countries). In 2011 the International Council for Science undertook a foresight exercise to develop scenarios for the future of science (ICSU 2011). The report recognized the power of ICT, the intellectual opportunities of global interdisciplinary collaboration, and the desperate urgency of transdisciplinary collaboration to bring science and engineering to bear on wicked societal problems of every imaginable sort (health, resource use, poverty, urbanization, water, climate change, and such), but in the end the analysis distilled to two dimensions: would science be organized in ways that *engaged* societal problems or would it be *detached* from them? And would states' interests be parochially *national* or embracingly *global* (ICSU 2011, 18)? Aggressive nationalism, science for sale in the marketplace, or the prevalence of national interests over global interests would produce a pattern of collaboration unlikely to meet global needs, or even oppose them. Only a science engaged with social purposes and supported by national governments committed to the common good would form the collaborations necessary to produce knowledge equal to the challenges ahead. ICT may be necessary for us to realize the dreams of Federico Cesi and the Lincei, but they are not sufficient.

STS scholarship will have much to study but little to do that will likely influence the macroscopic dynamics that are shaping science. No amount of scholarship will shift states' interests from the national to the global, or from detached to engaged. But science engaged with global challenges, as it must be if it is to inform the pressing issues of our day, will offer much of interest to STS scholars and will demand much in return.

For example, ICTs and other new forms of research technology make possible closely monitored, carefully studied, and adaptively managed collaborations that will be shaped by social researchers who study them in real time and provide continuous feedback about their progress. The nascent Science of Team Science initiative, currently more aspiration than accomplishment, will advance in partnership with studies of individual and group creativity (e.g., Amabile 1996; Farrell 2001) and with the increasingly sophisticated use of sociometric sensors and other devices that capture rich and detailed (and massive) data about the process and outcomes of interpersonal collaboration, coupled with the emerging tools to analyze extremely large data sets.

Diverse publics are also increasingly engaged in research. The era of epistolary science has passed, and for the last century science has been conducted mainly in universities and industry, increasingly under a regime of capitalism, economization, and neoliberalism. But in recent years a countervailing practice has emerged—"citizen science"—"scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions" (Conz 2006; ODE 2014). Amateur scientists have discovered new planets, assessed regional biodiversity, and uncovered intricate patterns of protein folding. There are also new trends toward crowdfunding of scientific research by the general public, particularly as governmental funding for science has receded in recent years (Meyer and Schroeder 2015). The rise of amateur science, citizen science, crowdfunded science, and other alternative patterns of organization call for us to reconsider the social contract of science and to reopen debates about who counts as a legitimate scientific collaborator, how scientific knowledge acquires practical relevance, and how public awareness and trust are achieved and sustained.

Finally, "open science" is on the rise, making the inner workings of scientific research accessible to all (Fecher and Friesike 2014; Meyer and Schroeder 2015, 175–186; The Royal Society 2012).[7] While open access is removing the cost and copyright barriers to published research, making it available to everyone with an Internet connection, open data also implies sharing data either before or soon after publication, which would transform the research process by opening it up. Such openness may redefine accountability in science by bringing unprecedented scrutiny to scientific claims and to the entire course of data collection, cleaning, management, analysis, and interpretation (Hartter et al. 2013). Still, these processes involve substantial costs and complications that may create new inequalities that derive from the need to pay for open access publication and/or data curation.[8] The Matthew effect is alive and well (Merton 1973).

In closing, we return to our points of reference: science is an increasingly organized, institutionalized, and managed form of professional work tightly woven into the fabric of society and tightly coupled to social purposes. Whose purposes? is the unavoidable but difficult question. Science organized to serve capital and the interests of the richest billion or so people in the world will look very different from science that is globally engaged and working in collaboration with the global south. Science of the first sort will become increasingly tightly coupled to the economic, defense, and well-being needs of a fraction of the world, whereas science of the second sort will engage diverse publics in varied places to collaborate on wicked problems that contribute to sustainability and social equity. Both forms will be imbued with values, but the values will differ sharply.

Whatever the driving purposes and guiding values, science will be an increasingly collaborative activity, with work organized in a wide spectrum of virtual and face-to-face formats. ICTs, collaboratories, synthesis centers, and forms of virtual collaboration that we can dimly imagine will likely shape the scientific future of the years ahead. Scientists may still feel a vocation for science, but that calling will probably lead to a highly structured and deeply capitalized and regulated workplace. The apparent freedom of ICT-mediated scientific work will be offset by the increased ease of surveillance.

Growth and specialization depend upon resources and purposes controlled by scientific decision makers and those in government who oversee their work. At this writing (January 2016) U.S. science budgets have increased modestly, while the cost of research—including the cost of oversight and accountability—continues to rise more rapidly, and research opportunities increase geometrically. With increasing specialization comes geometrically increasing opportunities for inter- and transdisciplinary integration or synthesis, adding an additional burden of organization and expense to budgets already strained. Priorities are inevitable, accompanied by increased accountability and demands for metrics of science that will evaluate progress and inform decisions. The structure of scientific knowledge and perhaps of scientific revolutions will be shaped by conscious decisions made outside the research context. And, of course, all this will offer myriad opportunities for studies of the social and epistemic organization of science.

Notes

1. Though historians had done so previously using documentary approaches (see Pickstone 2000).

2. While often working with different tools toward different ends, STS and bibliometrics have a long history of informing one another and are generally complementary enterprises (see Wyatt et al., chapter 3 this volume). The overlap and mutual relevance of these research areas is apparent.

3. For the study of disciplines, see Kohler (1982) and Lenoir (1997).

4. For paradigms, see Kuhn [1962] 1970); for social words, see e.g., Gerson (1983) and Clarke (1991); for epistemic cultures, see Knorr Cetina (1999); for thought styles and cultures, see Fleck ([1935] 1981); for ways of knowing, see Pickstone (2000); for styles of scientific reasoning, see Hacking (2002).

5. But these claims have also received important criticism (see e.g., Hessels and van Lente 2008; Tuunainen 2002).

6. See also the Fred Jevons lecture on "Fashions in Science Policy" given by Arie Rip on March 2, 2014, at the University of Manchester (https://www.youtube.com/watch?v=kKqX-5VOqLc).

7. Peer review itself is becoming more open through such sites as https://pubpeer.com.

8. For details, please see http://blogs.lse.ac.uk/impactofsocialsciences/2015/04/21/to-what-are-we-opening-science/.

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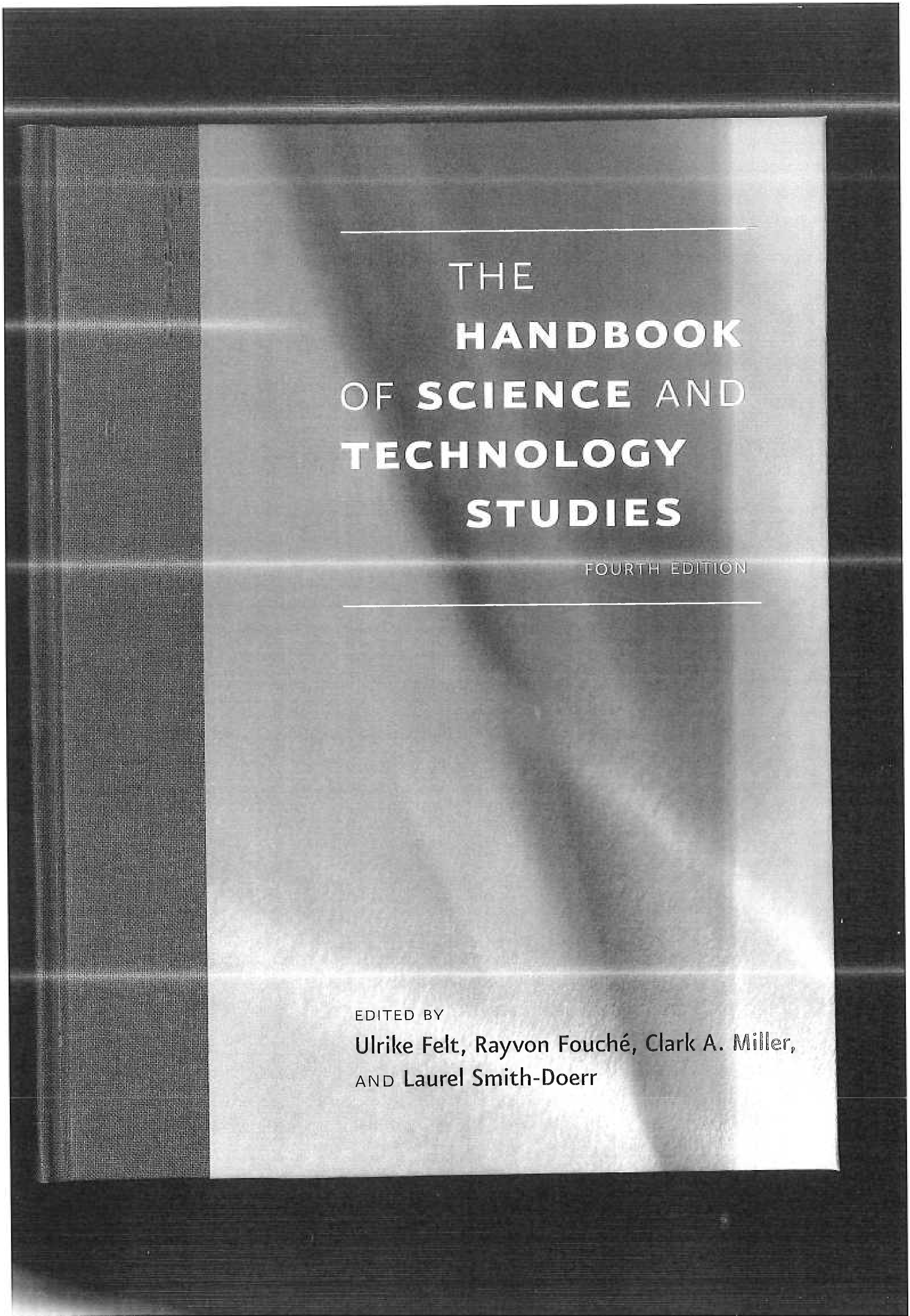
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