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Joerges, Bernward; Shinn, Terry

Veröffentlichungsversion / Published Version

Zeitschriftenartikel / journal article

Empfohlene Zitierung / Suggested Citation:

Joerges, B., & Shinn, T. (2002). The transverse science and technology culture: dynamics and roles of research-technology. *Social Science Information*, 41(2), 207-251. <https://nbn-resolving.org/urn:nbn:de:0168-ssoar-54934-6>

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Terry Shinn and Bernward Joerges

The transverse science and technology culture: dynamics and roles of research-technology

***Abstract.** Science and technology are composed of several regimes of production, each having its own research axis and mode of diffusion – the disciplinary regime, transitory regime, utilitarian regime, and transverse regime. This article discusses research-technology, an example of the transverse regime of cognitive and artefact production. Research-technologists stand between science and engineering, between academia and enterprise. They design and build a special category of instrumentation (open-ended, multi-purpose generic instrumentation) and they operate out of an interstitial arena that lies between the usual poles of interest and organization – university, firms, the state, military etc. By virtue of their interstitial position and development of generic multi-audience devices, research-technologists exhibit a highly dynamic division of socio-cognitive labor. They sometimes engage in boundary crossings, in order to acquire data for instrument design or for purposes of instrument diffusion. Conversely, they sometimes close borders, protecting themselves from the exogenous pressures of short-term audience demand. One sees that selective boundary-crossing is not inconsistent with community closure! This article outlines the history of research-technology in Germany and the US, shows how the research-technology perspective differs from the new orthodoxy in the sociology of knowledge, and points to how a better grasp of the workings of the division of socio-cognitive labor may prove fruitful beyond the sociology of science and technology.*

***Key words.** Boundary-crossing – Division of socio-cognitive labor – Instrumentation – Metrology – Research-technology*

In this article we present a frequently overlooked contemporary knowledge and artefact movement that incorporates features from both science and technology, yet remains distinctive from each of the two fields. We dub this “in-between” cognitive and technical tendency the research-technology movement.

Relations between science and technology are usually thought of in terms of five configurations: (a) science drives technology; (b) technology guides science; (c) science and technology develop independently from one another; (d) science and technology form a “dialectic” relationship in which they constantly push and pull at each other; (e) science and technology make up an undifferentiated continuous entity.

This article proposes an alternative understanding of the dynamics between science and technology. We argue that there exists an additional movement which operates between science and different forms of engineering, including production engineering, engineering-for-science and even social engineering. Such a community addresses important needs of both science and technology and may be seen as mediating interactions between technology and science. This point of view stands outside both the old and the new orthodoxies in the history and sociology of knowledge. It helps fill in key lacunae in dealings between technology and science, and furthermore resolves certain inconsistencies and incompatibilities in many conventional discourses on practices in science and technology and in the dealings of the two fields with other institutions, such as industry, the military, or state agencies.

As a discernible movement, research-technology first developed in Germany during the late 19th century (Shinn, 2001a), and then quickly spread to France, Britain, the US, and other technically, scientifically, and economically advanced nations. Research-technology practitioners are situated at the junctions between science, engineering, industry, state technical services, the military, etc. Because of their strategic location, they are able to provide key technical services to each of these communities. Research-technology thereby often makes itself indispensable to many audiences. The results of the investigations and endeavors of research-technologists take the form of open-ended, multi-purpose artefacts and methodologies. These are subsequently tailored by local users to suit specific needs.

The artefacts and methodologies elaborated by research-technologists spread out as they are absorbed by a variety of

technical/intellectual audiences in many institutions and geographical sites. The original hub artefacts and methodologies act as a template, which offers a common language and a set of shared images, performance expectations and evaluative criteria. In some instances, the artefacts and methodologies developed by research-technology may even take the form of a new paradigm. The shared language, images, expectations, and criteria fostered by research-technology permit individuals who are otherwise blinkered by the local technical practices of their restricted context to transcend their respective environments. They adopt part of the perspectives held in common with co-users of a shared research-technology. Research-technology is thus a cohesive force which neutralizes the effects of a highly fragmented world of ultra-specialization and incommunicability. Indeed, research-technology may be regarded as building and promoting a sort of social, technical, and cognitive universality.

This article will take up five aspects of research-technology. The first section deals with three of the field's fundamental components – generic instrumentation, intellectual and institutional interstitiality, and metrology. The second section sets forth some of the historical circumstances that gave rise to research-technology in Germany and the US and describes how research-technology operates. We specify the complex relations that occur between research-technology practitioners and scientists and engineers, and between research-technologists and other categories of instrument men.

The third section puts research-technology in historiographical perspective. We suggest that there exist numerous science and technology cultures – a discipline-related culture, a transitory culture, and a transverse science and technology culture. Research-technology is synonymous with the transverse science and technology culture. Differentiation, boundary-making, and divisions of labor prove central to the practices of all three cultures. Based on the roles played by differentiations and boundaries in science and technology cultures, this section critiques the radical anti-differentiation, seamless web and continuity tenets espoused by the new-orthodoxy-of-knowledge.

In section four we then demonstrate how the concepts of differentiation and the division of labor are crucial to an understanding of the functioning of generic instrumentation and interstitiality in research-technology. These concepts further enable us to grasp exactly why research-technology brings together a diversity of

scientific and technological disciplines, industry and state bodies, and how it permits them to communicate effectively. Research-technology is depicted here as a cohesive force that limits the intellectual and social fragmentation resulting from extremes in the division of labor and other differentiations.

In the final section we extend the cohesion and practice-based universality claims in a way to suggest how research-technology may emerge as an influential entity at the turn of the third millennium. We similarly suggest that the dynamic and plastic form of the division of labor that is particularly discernible in research-technology provides unexpected insights into the division of labor's internal dynamics and into the dynamics of professional and institutional boundary-building and the processes of cross-boundary communication.

Fundamental traits

How does research-technology differ from engineering and science? What sort of products are generated by research-technologists? How is research-technology organized, and does research-technology sustain itself? Why has it eluded the keen eye of science and technology observers for such a long time? A biographical sketch of Jesse Beams (1898–1977), one of America's foremost research-technologists, will suggest answers to many of these questions. Beams's research products and his career can indeed be regarded as emblematic of research-technology's contemporary operation. In the 1930s, 1940s, and 1950s, Jesse Beams developed the modern ultra-centrifuge. The device and the man do not fit neatly into any standard institutional, professional, or intellectual mold. Long-time chairman of the University of Virginia physics department, Beams also sponsored two firms, acted as a key consultant for four additional companies, participated in the Manhattan Project, worked for the military during the 1940s and 1950s, and contributed to numerous National Science Foundation science programs. Beams was not the classical academic, engineer, entrepreneur, or technical consultant. His strongest connection to the University of Virginia was the big, well-equipped workshops that he developed there (Brown, 1967).

The trajectory of Beams's ultra-centrifuge (Elzen, 1986; Gordy, 1983) paralleled his career. The ultra-centrifuge was a by-product

of his 1924 doctoral dissertation which focused on rapidly rotating mechanical systems. Assigned by his thesis director to investigate the speed of quantum absorption events, Beams developed a high-speed rotating technique for accurate time measurement for very short intervals. This device, and not the study of physical phenomena, was the centerpiece of his successful dissertation. An interest in multi-purpose, multi-audience technical apparatus, rather than a focus on the stuff of the physical world, emerged as Beams's guiding logic. Yet this focus did not make Beams an engineer or technologist in the usual sense of the term.

His initial devices employed air-driven turbines. However, their performance was limited by mechanical factors as well as by air friction. He first augmented speed by introducing a flexible drive-shaft which allowed for adjustments in the center of gravity, thereby multiplying rotating capacity. Next, he placed the rotating vessel inside a vacuum, thereby eliminating air friction. But shaft mechanics continued to jeopardize performance. To solve this, Beams employed magnets to spin his vessel. The vessel was suspended inside a vacuum, thanks to a magnet-based servo-mechanism. This constituted his consummate ultra-centrifuge, capable of rotating at unheard-of speeds.

The ultra-centrifuges became important elements in bio-medical research on bacteria and viruses, and they quickly figured centrally in medical diagnosis and treatment. Beams engineered devices for radioactive isotope separation in the late 1930s which were effectively tested in the American nuclear bomb Manhattan Project and became commercially viable in the 1950s and 1960s. The Beams ultra-centrifuge served in early ram jet propulsion research, and it was also used to do physics and engineering research on the strength of thin films. A Beams device rotating at over 3,000,000 revolutions per second was used by physicists to measure light pressure. A somewhat different instrument enabled enhanced precision in the measurement of the gravitational constant.

Beams published abundantly, sometimes in disciplinary periodicals, but much more of his written output appeared in instrumentation journals, like the *American Review of Scientific Instruments*. A high proportion of his writings took the form of unpublished technical reports. He co-sponsored half a dozen patents. Beams's written productions were equally divided between the public and private spheres: between articles and patents on the one hand (public), and confidential reports and consultancy on the other

(private). Concurrent with these publications, he continued to build far-reaching artefacts.

Beams crossed innumerable boundaries, circulating in and out of institutions and shifting from employer to employer. He belonged to many organizations, movements, and interests. He was neither a-institutional nor anti-institutional, but instead multi-institutional. He had no single home; his home lay everywhere. He explored and exploited the laws of nature embedded in instruments. Like Beams himself, his ultra-centrifuges also crossed a multitude of boundaries. They were open-ended, general-purpose devices, which came to perform a host of functions, and found their way into a variety of non-academic publications.

A special vocabulary and way of seeing events developed in conjunction with the Beams device. Microbes and viruses, light pressure and gravitation, isotope separation and thin films came to be spoken about in terms of rotational speeds and centrifugal pressures. “Rotation” emerged as a lingua franca for a disparate spread of fields and functions, extending from academia and research to industrial production and medical healing. The rotational vocabulary and imagery of Beams’s instrument spun outward. Beams’s approach and his artefacts thereby helped coalesce often dispersed technical, professional, and institutional worlds. Beams’s career and his devices embody three of research-technology’s underlying principles – generic design, an interstitial socio-institutional stance, and metrology.

Generic devices

Beams’s ultra-centrifuges were characteristically generic machines. The concept of genericity entails three elements (Joerges and Shinn, 2001: 9). First, research-technologists’ interest lays in instrument design, and in the modalities, regularities and laws that underpin instrumentation. Practitioners are less concerned with the laws of nature than they are with the laws that govern the conception, construction, and operation of precision apparatus. Genericity emphasizes practice – practices consistent with building and using apparatus which exhibit fundamental instrument principles. Secondly, genericity also refers to a form of instrument design that consciously takes into account maximizing the variety and number of end-users whose local technologies can incorporate key features

of a research-technology template. Through mastery of basic instrument principles, research-technologists invent open-ended, flexible apparatus that can potentially be adapted to a spectrum of narrow-niche applications.

Finally, the idea of dis-embedding is central to genericity. Dis-embedding refers to devising devices in such a way that they can readily be opened up (made fully transparent) and disassembled – later to be reassembled according to need. This is the very contrary of “black boxing”. Beams’s generic ultra-centrifuge was generic because it was a template for countless locally tailored kinds of centrifuges. The generic design was the point of departure for end-users’ recastings of their centrifuges through re-embedding relevant aspects of the generic design into the technical systems of their own particular contexts. This entailed extracting from the hub apparatus relevant elements which corresponded to local demand. Generic instrumentation thus incorporates a dual action of dis-embedding and re-embeddings. While dis-embedding design and practices comprise an epicenter of research-technologists’ endeavors, it is not rare for practitioners to become temporarily involved in the work of re-embeddings as well. Participation by Beams in re-embeddings occurred on several occasions in the course of his rich and diverse career.

The interstitial arena

Beams’s trajectory also points to the interstitial positioning of research-technologists. Beams worked at the University of Virginia, and he also worked for no fewer than 11 other bodies, some of them in public health, the precision instrument industry, aviation, the military, state metrological services, and public research. Beams’s activities were not determined by any single employment pole, nor by a combination of poles. He simultaneously or successively occupied a number of terrains, but always from the stance of a non-aligned position. In some respects, his stance was trans-institutional. Through associating with a variety and a large number of occupations, professions, and institutions, Beams succeeded in sustaining a high degree of vocational autonomy. His main commitment remained generic design. His identity was inextricably instrumental rather than institutional. By working for many interests, he worked for no one interest or institution in particular. It is by virtue of

research-technology's interstitial position that it is valid to say that its purview lies between science, industry, and the state (Joerges and Shinn, 2001: 7–8). Put differently, research-technologists manage to maintain generic instrumentation as their key perspective because they operate out of an interstitial position.

The interstitial position entails an additional important feature. Due to a centripetal current within the interstitial configuration, research-technology practitioners are able to garner ideas and information from an exceptional number and range of sources that can help guide research on generic design. Research-technologists do not design devices in accordance with end-users' technical requests and requirements. This does not signify, however, that end-user demands are not central. Precisely because practitioners are free to interact with innumerable audiences in a framework of non-constraining professional and institutional relationships, they can be selective and strategic in collecting information from multiple quarters – information which inspires novel ideas for generic artefacts and methodologies, information on the desiderata related to niche demand, and transverse information which ties demand in one domain to that in others, thereby suggesting fresh generic paths.

By contrast, a centrifugal current in the interstitial stance promotes the diffusion of template devices. Because research-technology practitioners are located between multiple interests and institutions, they are strategically placed to diffuse their artefacts and methodologies outward in all directions. This universalizing potential is generally beyond the reach of most other cognitive and technical bodies, whose range of contacts and influence is circumscribed by the defining practices and closed socio-institutional purview of specialization and expertise. This willfully organized self-restricting expertise is to be found in the purposefully self-differentiating social, intellectual and institutional arrangements of scientific disciplines or specialties, engineering and technical fields and professions, procrustean industrial sectors, government bureaucratic demarcations, etc. This strategic building of boundaries and circumscription of purview are the very opposite of the open interstitial configuration of research-technology, which is predicated on boundary-crossing.

Because of the centrality of the interstitial stance to research-technology, the movement aspires to be “distinctive” as opposed to “distinct”. While research-technology looks for recognition, it does

not seek institutionalization – and assuredly not a form of institutionalization which would exclude it from other bodies. Indeed, comprising a distinct movement, as opposed to a merely distinctive one, would potentially jeopardize research-technology by alienating the audiences whose instrumentation is rooted in research-technology's generic design and devices. Were research-technology to constitute a distinct force, the innumerable groups which assimilate its generic artefacts and methodologies might come to perceive the movement as a threat to their coveted and hard-won cognitive, technical and institutional autonomy. Although many groups within academia, industry, and the state depend on research-technology productions, each body also possesses its internal instrumentation-producing capacity. The latter generally tailors narrow-niche, non-generic devices to satisfy purely local technical requirements. But these instrument services sometimes exhibit higher ambitions. If research-technology were to emerge as a distinct force, jealousy could arise, and audiences might boycott research-technology or even attempt to encroach on it.

To avoid alienating user audiences, research-technology maintains a certain reserve. The community possesses structure, but has few institutional trappings or status. It tries not to be a target. To be engaged in adversarial relations is anathema. In order to remain above the *mêlée*, above disputes over turf often unendingly waged by scientific and engineering groups as well as by industrial and governmental institutions, research-technologists sometimes even opt for a measure of community "invisibility". This is fully consistent with the tenets of the interstitial stance, and such a measure drastically reduces the risk of jealousy and enmity. A last feature of research-technology's interstitial character warrants description. The practices and identity of scientists, engineers, industrial personnel, and people in public technical agencies are frequently tied to particular professional associations, and concomitantly to a restricted range of journals or alternative written technical forums. For example, American physicists belong to the American Physics Institute, and experimental physicists write for *Physical Review Letters* or similar journals. American electronics experts belong to the American Institute of Electrical Engineers, and publish principally in the institute's covey of journals. Industrial technical personnel take out patents and write for trade publications. Once again in the US, public metrological personnel have their consecrated periodicals; this is the case, for example, for the Bureau of

Standards. In each instance, the professional geography and scope of publication are strikingly restricted. In research-technology the situation is dramatically different.

There are no research-technology professional associations. The closest thing to such an association is the Instrument Society of America, but this organization is not a haven for research-technology. Membership consists mainly of narrow-niche instrument specialists and instrument engineers, although research-technologists are also welcomed.

Unlike scientists, engineers, industrial personnel and people in state metrology services, who join a few appropriate professional associations, research-technologists become members of a score of professional bodies. A single research-technologist may thus belong to professional bodies in five or six different scientific fields, to bodies in several industrial trade associations or in a number of engineering domains. Practitioners thereby use professional organizations to span separate intellectual communities and for facilitating boundary-crossing. Similarly research-technologists use an unrestricted variety and large number of vehicles to diffuse their generic artefacts and methodologies. While several journals have historically promoted generic apparatus, among them the *Zeitschrift für Instrumentenkunde*, the *British Journal of Scientific Instruments*, the *American Review of Scientific Instruments*, and to a lesser degree the *Revue Instrumentale Théorique et Appliquée*, practitioners nevertheless spread their output between these periodicals and the professional forums of science, engineering, industry and state technical services. Some research-technologists have published in over 40 different journals.

Publications can be seen as falling into two main categories – the public sphere and the private sphere. The public sphere includes academic and engineering journals and patents; the private sphere includes confidential consultancy recommendations, findings of contracted research, restricted-circulation company bulletins, and limited-circulation trade publications. The productions of research-technologists tend to range across the different sub-categories of each sphere. Moreover, in many cases productions are often relatively equally divided between the public and private spheres. Systematic recourse to such a complete spectrum of vehicles is a standard trait of research-technology, and is a direct outgrowth of research-technology's interstitial configuration.

Metrology

Metrology is central to research-technology on two grounds (Joerges and Shinn, 2001: 9–10). First, research-technology revolves around concrete practice. Practices include design, hands-on construction, endless tinkering and analysis to probe the deep principles of devices, adaptation to improve performance, explorations and controls to determine the extent to which a generic device can be generalized, trials and modifications to check whether the principles of generalization hold, and transferring apparatus into a local niche environment for tailoring and operation by end-users. Precision is all important here – precision in design, operation and extension. Equally crucial, the generic capacity of any template instrument involved in detection, measurement and control depends entirely on the refinement of its metrological potential in terms of exactness, stability, the physical variables dealt with, and the capacity to meter the variables in a range of different and often difficult environments. This is the substance of research-technologists' daily labors.

This concern with metrological practices highlights the second feature of research-technology's metrology link. The practices involved in the design, construction and diffusion of a generic device frequently give rise to the development of a new device-centered language. This is associated with the birth of new units of measurement or technical norms. In research-technology, the concept of "language" has to be construed in the largest sense. Hence, in addition to words, images and even gestures and protocols are developed. Generic instruments offer new ways of "seeing" a physical parameter or event. This way of seeing is generalized as the generic device spreads outward into diverse niche contexts. Similarly, operating techniques and protocols percolate outward from generic apparatus, and are integrated into the routine gestures of end-user operators in academia, industry, the military, state technical agencies and the like.

In the case of Beams's ultra-centrifuge, the vocabularies of revolutions per second and gravitational equivalents spread outward as Beams's ultra-centrifuge became implanted in diverse environments. Specialty groups in physics, aviation, engineering, biology and medicine learned to communicate and came to see aspects of their problem domains in the light of how Beams's instrument represented and dealt with the physical world.

The discovery of radium, and the concomitant development of radium-detecting apparatus and control devices, is another example of how a research-technology gives rise to new metrologies. The research surrounding radium involved the introduction of a new physical unit (the curie), new technologies, and the diffusion of radium and the technologies into a myriad of contexts – extending from chemistry to metallurgy, biology, medicine, and the military (Roqué, 2001). A specific set of terminologies, visual representations, and instrument practices, initiated with the discovery of radium and with early instrument design and construction, quickly became generalized. These soon moved outside the research-technology nexus and into many professions and countries. Here as elsewhere, various forms of lingua franca are part and parcel of research-technology, and this lingua franca constitutes the heart of metrology.

Origins of research-technology

When did research-technology first arise? Most well documented cases focus on the late 19th century, and more particularly the 20th century. In a pioneering study Sean Johnston perceived in the development of colorometry in the late 19th and early 20th centuries an episode which lay neither squarely in science nor in engineering, and which possessed many of the attributes that we conceptualize as research-technology. In France the construction of the giant Bellevue electromagnet by Aimé Cotton in the 1920s and 1930s (Shinn, 1993), with the establishment of an adjoining laboratory, constitutes a second example. Again in physics, several fascinating cases occurring in the 1940s, 1950s, and 1960s have recently been brought to light, including Fourier transform spectroscopy and liquid scintillation devices (Johnston, 2001; Rheinberger, 2001). In chemistry there is the electron capture detector, and in the sphere of biology an instance of research-technology has been identified in plant genetics (Morris, forthcoming; Nevers et al., 2001). Anti-lock braking and laser-linked spectroscopy are examples of research-technology in engineering (Johnson, 2001; Mallard, 2001). The first exhaustively documented episode of proto research-technology has been put forward by Myles Jackson in his study of Fraunhofer, who in the early 19th century introduced a technique for the manufacture of exceptionally homogeneous glass, and a

technique for quality control and standardization of the glass (Jackson, 2001).

The “when” question could perhaps be better formulated as: what were the dominant relationships between science, technology, engineering, industry, government and the military during the rise of research-technology movements? Put differently, what was the alignment of intellectual, technical, economic, professional, political and military forces during the birth of research-technology?

Four conditions have often favored the introduction of research-technology:

- (1) A context of national aggrandizement or heightened national political ambition, together with the emergence of an assertive military establishment, accompanied the introduction and reinforcement of a research-technology movement in late 19th-century Germany and in the US in the early and middle decades of the 20th century.
- (2) The instituting of research-technology in Germany in the 1870s and 1880s and in the US in the 1930s, 1940s, and 1950s occurred during a period of rapid and sustained economic expansion in science and technology-related spheres.
- (3) The chasm between science on the one hand, and precision and basic instrumentation on the other, as in Germany at the end of the 19th century and in France during the first decades of the 20th century, set the stage for the consolidation of research-technology.
- (4) The rapid development of multiple new disciplines in science, technology and engineering, and the development of new relationships between these entities, proved propitious to research-technology’s establishment. This was linked to the emergence of fresh cognitive and material combinations which bred generic innovations, and to the rise of many and diverse new spheres of generic device consumption.

The German research-technology nexus, 1860–1900

First in Prussia, and then in Wilhelmine Germany, a confluence of academic, technical, engineering, industrial, military, and governmental positions and policies spurred the rise of research-technology at the end of the 19th century. The circumstances of the rapid rise

of Germany's research-technology movement intersected with Prussian and German military history, and with an explicit refusal by the Berlin Academy of Science to become involved with precision instruments. It also entailed the growth of Germany's technology-intensive industry and a desire on the part of the government, state metrology services, and some instrument craftsmen to reinforce and promote a distinctive instrument movement.

During the 1860s, as well as afterward, the Prussian army was on the move – the Schleswig-Holstein conflict, the Austro-Prussian war, the Franco-Prussian war, colonial expansion into Africa and the Pacific, and subsequent assertive and expensive martial preparedness. The German general staff was quick to grasp the importance of technology and of precision instrumentation for communications, transportation, range-finding, and the standardization of equipment. In the Morozowicz report of 1871–2 (Cahan, 1989: 25–7), the general staff complained that Prussia's capacity in scientific instrumentation was woeful, lagging behind the capacity of France, Britain and in some fields the US. The report called for immediate action: Government must stimulate the country's nascent precision-instrument sector; the Berlin Academy of Science must intervene; steps should be taken within the existing precision-instrument arena to make it more dynamic, self-conscious, and productive. The future strength of the Prussian armed forces, the report concluded, depended increasingly on innovations and readiness in precision instrumentation.

The Berlin Academy of Science's 1869 response to earlier suggestions that it should open its doors to precision-instrument research and researchers, and should accord instrumentation investigations the same legitimacy as research in theory and experimentation, had already been very negative. A deepening and increasingly critical breach arose between entrenched pure academia and instrument-related initiatives. However, this negative attitude on the part of science to the incorporation of precision instrumentation into academia only bolstered a growing conviction among some Berlin instrument-makers that it was necessary to introduce an instrument movement having links with academia, yet not dependent on it, and having loose links with the military, industry, state metrology services and the like.

Strong support for research-technology came from Germany's state metrology services, and considerable work on generic devices was done inside those services, which included the State oceano-

graphic service and the Berlin Imperial Observatory. A second strand of metrology services also backed research-technology, namely, the Commissions for Standards and Norms operating in each of the Reich's Länder (Lundgreen et al., 1986). These commissions established industrial norms and standards, and controlled for safety. They constituted a hub for some instrument research.

W. Foerster, who held influential positions in the Prussian Ministry of Culture and who long directed the Berlin Commission for Standards and Norms, became one of German research-technology's foremost exponents (Cahan, 1989: 24–6, 29–31, 54, 57, 70, 75, 85–6, 110, 195; Pfetsch, 1970: 563–6; Poggendorff, 1863–1939). Foerster propounded the importance of general instrument research for the state, science and industry, and believed that this category of research could best be done on the margins of established institutions. He sat on the board of what would become two mainstays of the German research-technology movement – the *Gesellschaft für Mechanik und Optik* and the journal *Zeitschrift für Instrumentenkunde*. From these vantage-points he unceasingly promoted the cause of fundamental instrument investigation and the outward circulation of generic apparatus into a diversity of narrow-niche applications. Working together with L. Loewenhertz (Loewenhertz, 1880), another key figure on the Berlin Commission for Standards and Norms, Foerster in 1889 succeeded in opening the way for the *Gesellschaft*, *Zeitschrift* and research-technology at large to the leadership of the Technical Section of the newly founded *Physikalisch-technische Reichsanstalt* (Cahan, 1989: 39–42, 72–86, 121–5; Pfetsch, 1970).

Economic factors were also paramount in the development of German research-technology. During the final decades of the 19th century, industry in the Reich grew rapidly, sometimes by as much as almost 6 percent annually. Growth was particularly dramatic in certain science-and-technology-intensive sectors – for example, products linked to chemistry, optics, and electricity. The Siemens industrial empire is an instance of innovation and growth in the arena of electricity, and the Zeiss glass works of innovation and performance in the arena of precision optics. These and similar companies often provided the necessary outlet for the generic productions of German research-technology practitioners. Moreover, toward the turn of the century, some firms became centers of generic instrument research, as they tolerated the cognitive, technical and

social marginality necessary to personnel who engage in generic instrumentation practices.

Much of the credit for opening the way to research-technology belongs to German instrument craftsmen. In 1879–80 Berlin craftsmen specializing in precision optical and mechanics instruments set up the *Deutsche Gesellschaft für Mechanik und Optik*, and three years later the association founded the *Zeitschrift für Instrumentenkunde*.¹ This journal published articles on instrumentation, many of which escaped conventional disciplinary demarcations. It presented devices for biology, medicine, geology, surveying, academic and industrial optics, mechanics, chemistry, thermodynamics and electricity. A considerable portion of the texts reported on generic apparatus, and emphasized instrument laws in connection with possible ways in which template designs could be modified to fit into particular narrow-niche applications. A propopographical analysis of authors of generic articles reveals that in the 1880s and 1890s almost half of these texts were penned by craftsmen, and the remainder by employees of state metrology services, academics, and engineers or industrial employees – in that order. Two decades later, the profile had changed. The distribution between these groups became more balanced. The number of academics rose, and craftsman representation declined.

In the 1880s and 1890s, the *Deutsche Gesellschaft für Mechanik und Optik* attracted members from outside Berlin. Precision instrumentation grew into a nationwide current. Over the next 15 years the *Gesellschaft* took four major decisions which reinforced its generic and initial orientation. First, the body vigorously promoted instrument congresses and fairs, and participated in industrial and science fairs. In these forums, devices were increasingly exhibited in a way that emphasized their generic potential. Rather than exhibiting instruments in stands or pavilions organized around a theme or industrial sector as had been done in the past (electricity, transportation, geology, telegraphy etc.), instruments were instead exhibited in a single pavilion or stand which grouped all apparatus designed for detection, measurement or control. In this way, generic devices came to constitute a sub-exhibition, which emphasized their basic template characteristics and suggested ways in which apparatus might be modified to fit into particular end-market niches.

In a second key initiative, in 1893 research-technology activists succeeded in persuading the *Versammlung Deutscher Naturforscher*

und Ärzte to introduce a section which dealt with multi-purpose, generalist instruments. The *Versammlung Deutscher Naturforscher und Ärzte* was Germany's biggest and one of its oldest multi-disciplinary professional bodies, which included physicians from many specialties, scientists from a range of disciplines, and technicians. Within the body, each technical or intellectual domain had its own section, there being over 40 sections. From 1887 onward, the *Gesellschaft für Mechanik und Optik* petitioned the *Versammlung Deutscher Naturforscher und Ärzte* to open a generic apparatus section. In the past, there had been no place where instrument laws could be addressed per se: instruments had been treated as specialty devices inside each technical or intellectual section. The goal of research-technologists was not to establish research-technology as a new field or discipline: they intended that the instrument section become a trans-disciplinary site located between the established disciplines. To focus on generic apparatus automatically entailed multi-directional, transverse communication and practices. The 1893 *Gesellschaft* victory over the *Versammlung Deutscher Naturforscher und Ärzte* is an instance in which research-technology became distinctive without becoming distinct. It remained a trans-professional movement which straddled extant professions.

The last major decision of the *Gesellschaft für Mechanik und Optik* dealt with education. It became the focus of a heated and protracted debate over the advisability of developing in-house programs for training future precision-instrument designers and constructors, and transcending this issue it became the focal point of a second more general debate over whether specialized instruction in research-technology is indeed even possible. Between 1879 and 1891, the *Gesellschaft* set up and ran an in-house training program. It also opened an instrument workshop school in Berlin, where the sons of mainly craftsmen and shopkeepers, along with the sons of some industrial technicians, paid a low tuition fee for a two-year course. This consisted principally of apprenticeships in Berlin precision-apparatus companies but it also involved instruction in instrument design, drawing and construction. Arithmetic and low-level geometry were taught, along with mechanics and elementary optics, electricity and chemistry.

The *Gesellschaft* school encountered severe difficulties from the outset, and the experiment quickly terminated. The school attracted few students. Tuition fees were not high, yet expensive enough for

many students to request financial assistance. Initially, the *Gesellschaft* program scheduled more theoretical instruction, and instruction at a higher level in geometry, calculus, physics and chemistry. This plan was immediately abandoned, however, as most students lacked a sufficient background in these subjects. The youth who had the requisite learning often preferred to train in alternative technical institutions which offered well established career opportunities.

More general and theoretical objections to the *Gesellschaft* educational scheme were also voiced during the 1880s, along two lines. First, it was suggested that for intellectual and technical reasons it is not feasible to offer effective “specialized” instruction in research-technology which is open-ended and trans-specialist! While instruction in the design and construction of narrow-niche apparatus is certainly feasible, this is impossible for generic apparatus, as template instruments call on knowledge, techniques and skills from a vast variety of arenas – too many to be anticipated and included in even the most inclusive educational program. To circumscribe the pedagogical building-blocks of research-technology is to circumscribe its purview. Second, adversaries of the *Gesellschaft* Berlin school also protested on professional and institutional grounds, saying that all formal educational programs automatically identify and isolate their beneficiaries. Training and certification would quarantine research-technologists. Anything resembling demarcation would inevitably spell the demise of research-technology as a force between science, state and industry.

These arguments, along with the erosion of the finances of the *Gesellschaft* Berlin precision-instrument school, at last prompted closure of the school and workshop and the abandonment of reflections on specialized research-technology education.

The US research-technology experience, 1900–55

In the wake of the German experience, research-technology became a movement in other industrially and scientifically advanced nations. Clusters of practitioners emerged in Britain, France and the US between 1900 and 1950, and in the USSR and Japan between 1930 and 1960. The rise of American research-technology occurred over five decades. The trajectory was non-linear, and the resulting movement became large, omnipresent, and influential.

Five factors girded the development of research-technology in the US as a distinctive movement, which generated core devices for heterogeneous audiences from the vantage-point of an interstitial stance (Shinn, 2001b).

(1) The experiences of war (the First and Second World Wars, the Korean War and the Cold War) dramatized the nation's complete dependency on scientific apparatus, and these experiences brought home the centrality of scientific instruments in the civilian economy as well as on the battlefield.

(2) Just before and after the First World War, during much of the 1940s, and again in the early 1950s, many sectors of American industry grew at an unprecedented pace. In some years the rate of growth reached 6 percent, and in the areas of electronics and nucleonics annual expansion attained over 20 percent.

(3) During the 1930s, and particularly throughout the 1940s and 1950s, control engineering took off in America. Firms in a broad spectrum of industry, extending from photography and machine tools to telecommunications and manufacturing, increasingly used control engineering techniques in production. Control engineering hinged on feed-back effects, and in such effects detection, measurement and control are paramount. To improve these processes, ever more refined and reliable scientific instruments were developed. Generic instrument research and products permitted the expansion of control engineering by offering template devices which could be locally adapted to many engineering niches. Thus control engineering constituted an important market that favored the development of research-technology.

(4) Instrument interests and groups abounded in the US beginning in the 1930s, resulting in the birth of numerous instrument journals, a publishing house, and instrument-related associations. Research-technology groups gradually found a place in this complex constellation of interests.

(5) During most of the 20th century, new technical and scientific fields appeared in America and matured. Among them one can cite automotives, chemical engineering, electronics, radar and microwave technology, spectroscopy, laser technology, microbiology, cell biology, biological modeling, genetics, high-energy physics, and nucleonics. Some of these new fields were the fruit of novel scientific instruments. All of the fields, and particularly their interface with industry, stimulated instrument innovation. Part of this

innovation, and often its most key developments, entailed research-technology endeavors.

Between 1900 and 1955 the American instrumentation community prospered, giving birth to scores of instrument journals, to instrument trade associations, and to occupational and then professional organizations. In an ever more flourishing community of specialized narrow-niche instrument practitioners, it was difficult for instrument theoreticians and generalists to carve out a place for themselves, and only after much stumbling and numerous false starts did the essentially a-professional movement at last succeed.

America's first organization dedicated to instrumentation, the Scientific Apparatus Makers of America, was set up at the turn of the century. This body was a mix between an industrial trade association and an occupational forum. The organization published a manual listing instrument-making firms and offering information on products and their spheres of application; it also listed the names and addresses of instrument inventors and private consultants. The aim of the Scientific Apparatus Makers of America was to disseminate information and publicity for devices, as well as the more general message that instrument men were numerous and eager for orders. Manuals show little community consciousness or strategy. Narrow-niche devices constituted the mainstay, and instrument investigations, not to speak of research, did not appear. However, events connected with the First World War appreciably changed this apparently slow-moving state of affairs.

The weaponry used by American forces was increasingly technical, as were industrial processes involved in producing it. Mechanical and optical precision instrumentation lay at the heart of this transformation. Inventors and industrial engineers contributed importantly to precision development, along with academic scientists who played an historically unprecedented role in a military conflict. The creation in 1915 of the *Journal of the Optical Society of America* would within two decades considerably advance the US research-technology movement. The *Journal* bore witness to the recent institutionalization of optics in academia and to the aforementioned growing importance of optics in industry. An analysis of the articles appearing in it also reveals that throughout the period 1915 to 1930 a high percentage of texts specifically dealt with precision instrumentation rather than optical theory or experimentation. While academics gradually predominated, authorship in the journal was initially distributed among inventors, self-trained technicians,

engineers and university staff. Some academics – particularly theoreticians – expressed misgivings about the number of instrumentation articles appearing in the publication, and it was partly for this reason that in 1922 the journal established a special instrument insert to cater specifically to the flood of instrument-related research.

By the end of the 1920s, the quantity of instrument articles had outgrown the capacity of the *Journal of the Optical Society of America* to cope with them. Not only had the number of publishable pieces on precision devices become staggering, the purview of topics increasingly included fields outside of optics – fields such as mechanics, electricity, acoustics, and medicine/biology. In order to deal with this ever more diverse tide of instrument research, in 1930 the Optical Society of America and the National Research Council jointly founded the *Review of Scientific Instruments*. The *Review* published articles written by university personnel, independent technical consultants, industry-based technical staff, and employees of government technical services, such as the National Bureau of Standards. Articles on optics and electricity/electronics predominated during the 1930s. Soon, however, research specifically in electronics, magnetism, and nucleonics exceeded all other categories.

The 1930s occasioned a wave of instrument-oriented activities. Other national instrument journals appeared, among them *Instrumentation* and *Instrument Magazine*. These periodicals concentrated on precision devices which had applications in highly specific settings. Information about the operating characteristics of apparatus was provided, as well as information about the companies that manufactured equipment. The focus was a blend of instrument advertising and ideas about where and how devices were to be used. In this respect, *Instrumentation* and *Instrument Magazine* followed in the footsteps of the Scientific Apparatus Makers of America. There was indeed scanty reporting on research, and even less interest in generic instrumentation. Research-technology had no representation in this quarter.

Nevertheless, by the late 1930s the topography of the instrument community began to show clear signs of change. In 1935 a group of east coast academics and industrial consultants, industrialists, and instrument-makers set up the Instrument Publishing House. It published instrument manuals and books, and it also hosted instrument seminars and regional conferences. While much of the publishing house's endeavors highlighted narrow-niche application

devices, a significant portion of the body's activities were nevertheless given over to fundamental instrument investigations and the promotion of generic devices. Frequently stimulated by the Instrument Publishing House, scores of seminars were organized on the east coast throughout the late 1930s and 1940s to examine the underlying principles of basic instrumentation. These meetings brought together academics from top universities (MIT, Harvard, Columbia and particularly the Carnegie Technical Institute and the University of Pittsburgh), instrument consultants and industrial specialists. This turn of events was connected with several developments – the rise of control engineering, the golden age of science-intensive engineering and the nationwide organization and proto-professionalization of the US instrument community.

Control engineering became an increasingly important arena, and it enjoyed a remarkable rate of growth. Control engineering's first successes lay in chemical production. Its promise of precision, high productivity and quality, and its techniques spread quickly into areas of mechanics, electricity and electronics. The Brown division of the Honeywell Company, located in Minneapolis, Minnesota, became a leader in control engineering during this period. The firm's sphere of activity proved considerable, both geographically and in terms of the industrial sectors in which it installed devices. It can be documented that a strong bond – perhaps even a decisive one – came to exist between control engineering, the reinforcement of the instrumentation community in America, and the growth of US research-technology. The experience of Eastman Kodak is illustrative.

During the 1940s, the company decided to introduce control engineering into many of its plants. The firm's management brought in instrument and control engineering consultants, purchased the required detection, measurement and control apparatus, and employed new personnel. It also set up an in-house instrument division to generate future control engineering equipment. While control engineering became a key component of Eastman Kodak's routine operations, the instrument division did not succeed in designing devices. In response to this dilemma the Eastman Kodak company increasingly supported exogenous, independent instrument research into wide coverage and general instrument systems. In so doing, management hoped to encourage a technical and intellectual culture out of which would eventually come admittedly generic apparatus, but apparatus that could subsequently be trans-

formed to suit Eastman Kodak's local control engineering demands. Eastman Kodak was just one of many enterprises recognizing the centrality of research-technology and drawing on its resources.

On a different plane, the late 1930s, 1940s, and 1950s were a first golden age of science-intensive engineering, which immediately and dramatically reshaped the landscapes of scientific research and the economy. The advent of high-energy physics and nucleonics, just to mention one area, triggered a huge demand for new kinds of detection, measurement and control apparatus. While a large share of the devices were the product of local needs inside a university laboratory, a government metrological agency, a military installation, or a firm, nevertheless many crucial devices in nucleonics (such as the Lyle Packard liquid scintillation counter) belonged to the family of generic apparatus. Such devices were built on fundamental instrument principles, and this fact allowed them to be dis-embedded and then re-embedded in a variety of environments. Throughout the late 1940s and 1950s articles about generic instrument research in the field of nucleonics became so abundant in the *Review of Scientific Instruments* that the emerging technical area competed with generic research in electronics in terms of the number of publications.

For almost a decade the US instrument community gradually evolved in the direction of occupational organization on a national scale, and some instrument practitioners came out in favor of the professionalization of instrument careers. The Instrument Society of America was founded in 1948. The first step in its foundation took place in 1937, when the Instrument Publishing House and the Metallurgy Department of the Carnegie Technical Institute combined forces to sponsor a national congress in Pittsburgh devoted to scientific devices. Much of the cost of this meeting was underwritten by the Brown division of the Honeywell Company. The meeting attracted participants from academia, government, the military, industry and commerce. In 1939 the Carnegie Technical Institute's Chemistry Department and the Instrument Publishing House sponsored a second national congress, again held in Pittsburgh. It drew an even larger public. As a direct spin-off of these meetings, the American Society for Measurement and Control was set up in 1941. It continued the efforts initiated in 1937 and 1939 to bring more people into the instrument sphere, and was more tightly coupled to academia than predecessor bodies such as the Scientific Apparatus Makers of America had been.

Despite these gains, the Instrument Society of America was hurriedly set up in response to fears among some instrument practitioners that narrow-application, restricted-niche instrument manufacturers and instrument users might soon come to dominate America's instrument landscape. Richard Rimbach, a key architect and long-time leader of the Society and a central figure in the Instrument Publishing House, had striven for many years to extend the purview of the generalist instrument-maker in America. Rimbach recognized that research-technology could survive and prosper only if it was accepted by potentially competing end-user instrument groups. For almost a decade, he had envisaged an instrument collective in which end-users figured prominently and where generalists could also prosper. It was this vision that spurred Rimbach to participate in the creation of the Instrument Society of America.

The Instrument Society of America membership included chapters from all across the nation. By 1955 there were over 200 chapters, many of them listing over 100 people. The Society organized thematic workshops as well as regional meetings and an annual instrument conference, and, beginning in 1950, it set up international instrument conferences on a periodic basis. In 1954 it founded its journal, the *Instrument Society of America Journal*, which appeared monthly. Starting with the inaugural issues, it carried employment advertisements for scientists, engineers and technicians with experience in "basic" or "fundamental" instrument research, placed by the National Bureau of Standards, the US Air Force, some universities like the University of Virginia, and some big firms, such as General Electric, Bell, and Eastman Kodak. Alongside employment advertisements for research-technology practitioners, was a profusion of employment offers for experts in narrow-niche instrumentation targeted at personnel for the operation, modification or occasionally the design of such equipment. However, what were relations like in the Society and the *Journal* between generalist, template instrument designers and the experts in narrow-niche, end-user apparatus? The question arises: how did the US research-technology movement fit (if it did at all) into the nation's broader instrument community?

In a series of articles appearing in the *Instrument Society of America Journal*, Rimbach and other editorial board members and certain contributors specifically and warmly welcomed the presence of generalist instrument practitioners inside the American instrument movement (Akins, 1954; Batcher, 1954; Brand, 1954; Brombacher, 1954; Draper, 1954; Fletch, 1954; Lee, 1954; Lucks, 1954;

Web, 1954). They insisted that “instrument generalists” (sometimes also referred to here as “instrument theorists”) were crucial to the future of American science and industry, and to the strength of the nation’s armed forces. Generalist instruments were portrayed as devices that fueled academia, the economy, and certain state functions. Open-ended flexible generalist equipment promoted technical life through facilitating operations and further advances. Rimbach and his allies wrote that while the overwhelming majority of the members of the Instrument Society of America admittedly designed, made or operated narrow-application devices suited to the needs of a specific local setting, a very much smaller group of practitioners was engaged in instrument theory and the design and construction of template devices. The resulting equipment was intellectually, technically and methodologically fundamental, as it often provided the seed ideas, techniques and protocols for the apparatus that was developed and used by downstream instrument experts in their important endeavors. The work of the generic instrument designer and that of the narrow-niche instrument practitioner were thus deemed to be fully complementary. There was no justification other than a misplaced fear of encroachment and rivalry (such as had sometimes unfortunately shadowed the dealings of earlier instrument bodies), wrote Rimbach, for narrow-niche instrument makers to attempt to bar instrument generalists’ and theoreticians’ access to the Instrument Society, nor to seek to drive them from it. Such action would only prove harmful to all.

In the same series of early 1954 articles, the authors pointed to the peculiar “multi-position”, “floating”, and “mobile” stance of practitioners who design and build template instrument systems. Many big science and technology-intensive companies possess instrument divisions, in which scientists and engineers conceive and construct devices for use inside their firm in line with a specific technical need. Alongside their instrument division, some companies also set up an instrument sector, loosely overlapping with the instrument division, but obeying a very different logic. In an instrument sector, practitioners articulate fundamental instrument theory and develop template instruments which are open-ended. The resulting design or physical apparatus are offered to the firm’s instrument division or to other divisions within the firm, where they are then re-designed and adapted to fit a well defined task. Designers of core devices operate between established company structures, moving in and out of them at will. These people also frequently

move between the firm and universities, the military and government. This category of instrument-men operates in a transverse arena, which enables them to funnel in data and ideas from countless quarters and disseminate template methods and artefacts across countless boundaries. From the standpoint of company accountability for generic technical productions, the designers of core equipment stand outside the usual company command stream. They are not answerable to any functional or technical authority, but only to top management. In effect, research-technologists are almost free agents.

The American and German experiences in research-technology document the importance of an interstitial arena. These case studies also demonstrate the great degree to which research-technology revolves around genericity, at least to the extent that it shapes group identity. The events that occurred in America and Germany similarly reveal the centrality of metrology as a perspective for developing basic instrument principles and crafting template devices on the one hand, and for providing a technical, economic and discursive platform for disseminating the devices on the other. Taken together, rapid economic growth, the birth of new scientific and technical disciplines, the quasi-refusal of academic science to take charge of generic instrumentation, a phase of national expansion, and a lively pre-industrial instrument tradition form affirmative ingredients for the emergence of a national research-technology movement.

These case studies also draw attention to the emergence of some strange cooperations within the broad instrument-making community. The community is acutely heterogeneous. It includes narrow-niche instrument designers, instrument manufacturers, a variety of users, and only a relatively small number of template designers and constructors. Rivalries and misunderstandings abounded in America and Germany. Nascent research-technology was often shoved aside. Only the occurrence of strange relationships between the various instrument parties eventually enabled research-technology to jell to the point that it emerged as a historically discernible, distinctive arena.

Research-technology in historiographical perspective

Where does research-technology fit in the history of science and technology? Is it an old form of intellectual/artefact production

that has until recently just gone undiscerned? Alternatively, is research-technology instead one crystallization in a new and novel configuration? Perhaps more to the point, have the existence and operation of research-technology rather been masked by low sensitivity among some scholars to certain structures and rules that underpin the dynamics of science and engineering, and their interactions with other cognitive, material and social modalities? One layer of the answers to these questions is to be found in the ways that historians and sociologists perceive and represent science and the growth of scientific knowledge. Since the 17th century, science and technology have been dominated by three regimes: discipline-related science and technology culture, transitory science and technology culture, and transverse science and technology culture. The study of discipline-related science and technology culture has emphasized institutional and professional elements in the growth of scientific knowledge and distinguished between science and engineering. Analyses of transitory science and technology culture maintain the idea of a demarcation between academia and engineering, but at the same time show how practitioners pass back and forth between the two arenas. Transverse science and technology are synonymous with research-technology.

The history and sociology of science and technology have largely been written in the framework of discipline-related science and technology culture. Innumerable monographs explore the birth, maturity and occasionally the terminal phase of disciplines like astronomy, chemistry, ecology, engineering specialties, phrenology, geology, physics, and micro and molecular biology (Gingras, 1991; Heilbron and Seidel, 1989; Kevles, 1978; Lemaine et al., 1976; Mullins, 1972; Nye, 1993; Rheinberger, 1997). The sheer volume of such scholarship is so abundant and omnipresent that the inattentive observer of science might erroneously conclude that the history of modern science is principally the history of discipline-related science, although in truth all three science cultures have operated and co-existed for at least 150 years.

There are sound reasons for the historiographical emphasis on discipline-related science and technology culture. Disciplines are structured around relatively easily identifiable and stable institutions, and disciplines, like most other institutions, produce and leave behind a voluminous paper trail which renders more manageable disciplinary analysis. Science disciplines are rooted in the institutions of laboratories, university departments, journals, national

and international professional bodies, conferences and congresses, procedures for certifying competence, systems for awarding prizes, formal networks and unofficial connections, and so on. Markers like these facilitate the detection and analysis of certain career patterns and certain categories of scientific production. Moreover, the shared centrality of institutions both for discipline-related science culture and for more general societal operations and events smoothes the path for establishing connections and parallels between science and beyond. It is in this frame that terminologies and notions from non-science realms, such as political life, have been used to probe the world of science. The classical work of Thomas Kuhn is a case in point. Richard Whitley's (1984) studies of the social and intellectual organization of a large number of scientific disciplines has likewise borrowed crucial vocabularies and insights from the organizational structures of non-science institutions and extended them to the landscape of science's discipline-related culture.

Despite their successes, studies of discipline-related culture have proven insensitive to other equally important cultures in science. This is precisely because an immense amount of science occurs outside the disciplinary matrix – science which instead occurs on the periphery of established institutions. This science is not free from institutions and the effects of differentiations, but it does deal with them in highly complex ways which are sometimes overlooked or misunderstood. Indeed, many careers and much cognition take place in a transitory science and technology culture which is not systematically congruent with orthodox disciplines, institutions, divisions of labor or other forms of differentiation. While in a few respects transitory science and technology culture resembles transverse culture, the latter is nevertheless a distinct mode of production.

Intellectual, technical and professional opportunities sometimes arise near the periphery of orthodox fields, and in such instances effective research or career-making requires practitioners to step temporarily across the boundary of their home discipline, as they seek techniques, data, concepts and colleague co-operation from neighboring disciplines. Most of the time, the quest for incremental cognitive, material or human resources entails two, or at the most three, disciplines. Practitioner movement consists of a to-and-fro oscillatory pattern. The trajectory is circumscribed with respect to both time and the extent of movement. Of utmost importance to transitory science and technology culture, scientists' principal center

of identity and action remains a discipline, even though individuals do traverse fields.

The transitory science and technology culture subsumes two different yet related trajectories. The life and work of Lord Kelvin are emblematic of one pattern. Norton Wise has documented precisely how Kelvin changed from physics to engineering and from engineering back to physics (Wise and Smith, 1989). As perspectives opened, the man shifted territory. Nevertheless, Kelvin's itinerary remained circumscribed. Moreover, from the standpoint of both the historian and the professional scientist, Kelvin's fundamental allegiance and identity remained discipline-bound, entwined with the orthodox discipline of classical physics. Alternatively, transitory science and technology culture leads to the derivation of a new sub-discipline, as in the cases of physical chemistry, biochemistry, biophysics, astrophysics, and geophysics. The list of such creations is long and deeply rooted in the practices of science and technology. In these and similar cases, the above-described oscillatory trajectories of practitioners terminate in the establishment of a novel field – a conjunction of two or several established fields. The new sub-discipline is the consequence of the transitory science and technology culture. In order to understand this culture and its intellectual/technical productions, the historian and sociologist must above all focus on interfacing and motion. But let me repeat, in this culture movement and interfacing are strictly, albeit admittedly indirectly, defined and regulated by the disciplinary referent. The themes of institutions, divisions of labor and differentiation remain paramount, although they are played out in a specific manner. Careers are mobile, and knowledge is fluid; but both operate in a confining and restricted set of co-ordinates.

In transverse science and technology culture the degrees of freedom and the scope of action of practitioners are far greater than in the transitory science and technology culture. For the purposes of this analysis, we will consider research-technology as an exemplar of this last mode of knowledge/artefact production. As documented above in this section, research-technology extends back at least one and a half centuries. It emerged in Germany, Britain, France and the US; and in each of these sites and during each historical period it operated alongside the discipline-related and transitory science and technology cultures. The three cultures may in fact be regarded as mutually interdependent and as nourishing one another.

If, as we propose, transverse science and technology culture, in the guise of research-technology, has been around for a long time, and has moreover often proven important to the growth of scientific knowledge and technologies, why then is it so conspicuously absent from the historiographical picture? Why have historians and sociologists often overlooked its very existence? Part of the answer to this question derives from the fact that participants in transverse science and technology culture are “moving targets”.

Research-technology practitioner association with institutions, employers and disciplines is normally fleeting. The paper-trail needed to document their trajectories is therefore fragmentary, making sociological and historical investigation problematic. The difficulty of sound research is further exacerbated by the existence of multiple and diverse vehicles for practitioner productions. Indeed, moving targets are never easy for scholars to fix or trace. For scholars whose investigations are rooted in the detection and analysis of stable institutions and sharp divisions of intellectual and material labor, the operations of transverse culture prove difficult and unmanageable. But the contrary is also true: for scholars who refuse all gradations of differentiation and divisions of labor, the subtleties and regular structures of research-technology similarly go largely undetected.

Transverse science and technology culture is characterized by several elements. Practitioners principally draw their identity from projects rather than the disciplines or institutions that they frequent. The perpetuation of well grounded institutions, in the form of academic and technical professions and employers, remains fundamental to this culture. Such defined settings provide necessary input for fresh projects in the form of ideas and information. They also validate and consume the cognitive/technical products of the participants of the culture. An arena of action in which practitioners are relatively free to shift about constitutes the social and material space wherein novelties may be generated outside the constraints of short-term demands. Transverse culture furnishes the social and cognitive cement that enables the more fragmented and dispersed entities constitutive of discipline-related science and technology culture and transitory culture to communicate with each other and to generate trans-field intelligibility.

The characteristics of transverse science and technology culture overlap so strongly with the features of research technology that they may be seen as synonymous. Two advantages are gained by

generalizing research-technology into a fundamental science and technology culture. First, research-technology's place in history, and its historiographical status, are clarified. Second, functionally speaking, certain lacunae and contradictions in the operations of discipline-based and transitory science and technology cultures, and the relationships between them, are explained and resolved.

These three cultures share key elements. Each is predicated on a division of labor – intellectual, technical and social labor. While the various science and technology cultures each manage the division of labor along different lines, the division of labor nevertheless remains a general foundational force. It allows the concentration of effort and specialization. In addition to the division of labor, differentiations between the culture of science and technology and other proximal social and intellectual cultures are paramount. Such differentiations have enabled practitioners of technology and science to define their objectives and to sharpen skills. They have permitted them to survive attack and periods of fallow. Of course, differentiations also act as a corporatist system of defense, and eventually as a mechanism for procuring privilege and ascendancy. In the pages that follow we will suggest that the indifference of many new-orthodoxy-of-knowledge scholars to the problematic of the division of labor and differentiation has caused them to misjudge the category of endeavors associated with research-technology and to misread many aspects of technology and science in general.

Differentiation and the division of labor – a critique of the new orthodoxy of knowledge

During the last 25 years a new orthodoxy in the sociology of scientific and technological knowledge has emerged. Two arguments prove central to this new orthodoxy. First, historians and sociologists perceive the whole of human activities as a “seamless web”. This anti-differentiation stance denies distinctions between scientific endeavors and other spheres of social organization and human performance. According to the tenets of anti-differentiation, the work of exacting laboratory measurement and theory development, science popularization, back-room politicking to raise money, awarding prizes in science, instrument design and construction, the delivery of public addresses, the critical evaluation of research findings etc. all constitute a smooth continuum, where there are

no boundaries and performance is achieved uniquely through the power of rhetoric, budgetary outbidding, and professional power. The anti-differentiation tenet of the new orthodoxy correctly stresses the existence of a profusion of frequently closely connected layers of social action and interaction. In science as elsewhere, the quantity of layers is staggering, and the gradations between layers is sometimes highly nuanced. Despite this reality, denial of social and cognitive differentiation by the new orthodoxy school is misguided, a misreading of social organization and practice (Knorr-Cetina, 1981; Latour, 1983; Latour and Woolgar, 1979; Lynch, 1997; Merz and Knorr-Cetina, 1997; Pickering, 1984, 1995).

From a certain perspective, the misunderstanding is explicable. The denial of the operation of stable and bounded groups and institutions as key components in social dynamics is a misobservation based in part on difficult-to-interpret recent social transformations. Indeed, throughout the 20th century, and particularly since the Second World War, innumerable additional movements, groups and institutions have come to the fore. The social and institutional landscape has become not only crowded, but also jumbled and chaotic. Supplementary social bodies and institutions have been created; intermediate bodies have followed; and extra intermediate bodies have been introduced to mediate between the former generation of intermediate institutions and groups. The once relatively considerable distance and demarcation between different bodies have diminished and even closed, thereby sometimes masking the distinctiveness and distinction of players.

This already confusing and disorderly picture is made more complex by the growing quantity of communications that flow between the constituted social bodies. Today, communications are not only more numerous, but they are also spread out in an infinity of directions. The technologies of land-line and radio telephones, satellite transmission, Internet, intranet and email, electronic, optical and infra-red paths etc. testify to this profusion. To this must be added the fact that communication itself has become multi-layered. Communication channels, messages and meanings are increasingly entangled. It is easy for us to understand how this complex configuration has led some historians and sociologists to describe social order and dynamics in terms of a completely undifferentiated unit. Glimpsed from a certain angle, the thing looks to be a whole, a seamless web, a continuum, but this representation is largely a mirage, an optical illusion, stemming from the misreading of events.

We emphasize here that the issue of anti-differentiation versus institutions and social and intellectual boundedness is essentially an empirical one, and that it is long overdue to treat it accordingly. The objects of dispute between these two fundamental perspectives are thus susceptible to measurement. There exist time-tested techniques for detecting social movements, bodies and institutions, and cognitive and social boundaries; and for identifying and analyzing their internal operations and interfaces. Why not appeal to empirical devices rather than relying on impressions and appearances as a technique for settling immediate concrete sociological and epistemological issues? Sadly though, in the course of preaching postmodern doctrine, the quality of scholarship of some new-orthodoxy-of-knowledge purveyors has occasionally become an unintended victim of lax or questionable empirical work.

In addition to the sometimes dubious empirical base of their endeavor, the methodology preferred by practitioners of the new orthodoxy in the history and sociology of science and technology is also at fault. It is excessively restrictive and blinkered, designed mainly to detect and explain how cognitive and technical actions initiated in one sphere achieve extension into other realms – in effect, how they gain ascendancy outside the context of their origin. Concrete examples include: how scientists turn to any fashionable research topic solely in order to ascend the professional ladder; how scientists maneuver and scheme to achieve the credibility required to win a Nobel prize; how good science consists of generating a long, broad and thick network; and how scientists forge alliance with inanimate objects as a means of extending their point of view.

According to new orthodoxy advocates, there is but one set of rules that underpins science – transcendent ambition allied to war-like, strategic rhetoric and power-wielding. In elucidating the admittedly important dynamic of extension, the new orthodoxy has contributed significantly to sociological analysis – but unfortunately at the expense of rejecting the crucial fine balance that exists between the functions of extension and the equally central function of the internal doings of scientific bodies, the latter having boundaries and possessing specific sets of norms and rational evaluative procedures. In overlooking and obfuscating the particularities of different bodies, and by denying their very existence, the new orthodoxy repudiates a key aspect of cognitive and social life. There is abundant and compelling historical and contemporary evidence for

thinking that diversity and autonomy do indeed exist and, moreover, that they are compatible with the currents of social and intellectual homogeneity and unity which also characterize today's life.

By accentuating the tenets of anti-differentiation and extension, the new orthodoxy has turned its back on the centrality and permanence of historical institutions, and on the boundaries that demarcate groups of actors, along with the particular goals and procedures of the latter. In so doing, the new orthodoxy has demeaned the principle of the division of labor. This calculated rejection extends to three arenas – the social division of labor, the intellectual division of labor, and the division of labor that regulates the interactions between the cognitive and social spheres.

Generic instrumentation, practices, and the division of labor

What role does the division of labor play in research-technology? What fresh insights does research-technology provide into the operations of science and technology, particularly in opposition to the radical anti-differentiation and continuity messages proffered by the new-orthodoxy-of-knowledge? Inside research-technology the operation of differentiation and the division of labor are complex. The division of labor and differentiation function on two interacting levels with respect to practices of designing and dis-embeddings of generic instruments by research-technologists, and with respect to practices of re-embeddings of generic equipment by research-technologists together with practitioners outside research-technology. One level of action occurs deep inside the interstitial arena, while the other takes place at its periphery. Multiple subtle stances toward differentiation and divisions of labor are thus linked to the practices of designing, building and diffusing generic instruments. These stances are mirrored in the successive positions that research-technology practitioners occupy in their interstitial work arena.

That portion of research-technology endeavor which directly involves production of templates strongly invokes divisions of instrument labor. Practitioners require distance from end-user demands and pressures. This is necessary to the development of fundamental instrument theory and to the design of generic equipment. Protection and tranquillity are essential components. There is thus a positive correlation between commitment to differentiation

and divisions of labor among research-technologists and their focus on core devices.

By contrast, when research-technologists operate in proximity to the boundary of the discipline-based and transitory science cultures, industry or the military, they emphasize the value of mobility and fluidity rather than sharp and stable separations between cognitive and artefact bodies and professional differentiations. These near-boundary dealings characteristically occur at two phases in research-technology programs and are bi-directional: when practitioners seek concepts, information and project themata from potential local users, and when practitioners engage in the process of demonstrating how a generic device can extend to specific local requirements. Success of transverse action entails a temporary lowering of the barriers that define and defend fields. This is true for exportation as well as for importation.

This two-phase bi-directional movement in the interstitial arena that is associated with the intermittent suspension of differentiations may be discerned in the research-technology trajectories of Jesse Beams. Whilst drawing information and ideas inward that became the theoretical components of the ultra-centrifuge, Beams ignored disciplinary, professional and institutional differentiations. In the course of a succession of opening investigations for his generic device, he opened avenues of communication and co-operation in the fields of low pressure physics, vacuum engineering, control engineering, cybernetics and magnetism. The resulting flux of heterogeneous concepts and techniques proved essential to Beams's generic instrument theory of friction-free non-mechanical high-speed rotation.

However, this instrument theory was conceived and elaborated, and some of its general consequences derived, in strict cognitive and social isolation from disciplinary encroachments. During this conceptual and dis-embedding period, Beams worked according to rule – to the generic rules of research-technology. The vistas of instrumentation principles, and not applications, governed his actions. In a word, he clung to the generic instrument referent and therewith shielded himself from intrusion from other quarters. Beams was effectively bounded by the high walls of research-technology's division of labor and set of differentiating guidelines.

Thanks to the formal and codified character of the instrument theory, Beams could dis-embed features of his core apparatus in response to need and opportunity. Upon completing his template

device, Beams then reversed the direction of movement with respect to boundary crossing. He again traversed multiple boundaries, but this time along an outward bound path. In the course of re-embedding his template device, Beams once again ignored divisions of labor and differentiations customarily associated with nuclear energy, aviation design, medicine, pure physics and biology, and metrology. The bi-directional boundary crossing by research-technologists in turn also induces a partial and temporary relinquishing of the customary attachment to differentiation and divisions of labor among industry, metrology and military practitioners and practitioners of the discipline-based and transitory science cultures, during the periods when they are engaged in generic instrument acquisition or in the tailoring of generic devices. However, once acquisition is completed, the members of these professional communities once more ground their practices in the division of labor. From this, one sees that research-technology intermittently spawns, or at least overlaps with, local and temporary attenuations in community differentiations and divisions of labor.

Gradations of commitment to divisions of labor and differentiation occur through the intermediary of the interstitial arena in which the multiple facets of research-technology work are carried out. Practitioners are free either to maintain their “in-between” position which constitutes the necessary medium and environment of generic practices, or to move in and out of alien science cultures, industry and the military. They can slip in and out of institutions, research projects, or paradigms whenever required, but can also structure practice around a generic instrument-based imperative and division of labor and vocational differentiation. This is less of a contradiction or paradox than a structural adaptation to a complex set of intellectual, material and social relations which have evolved as the science and technology system and social order have expanded in size and become increasingly complex and differentiated.

Generic instrumentation, re-embeddings and cohesion

One impact of generic instrumentation is the stimulation of social and intellectual cohesion. In turn, these forms of cohesion sometimes give rise to a brand of universality. The adoption by an end-user audience of a generic instrument entails the audience's

integration of the protocols which make the instrument effective. Normally, protocols are embodied in widely accepted metrologies. Metrologies are constitutive of both the protocols and the vehicles that diffuse and legitimate them. Instrument users implicitly incorporate working concepts, beliefs about why the instrument is effective, and ideas about what it can and cannot do; and they incorporate functional vocabularies, images and so forth. Any given generic instrument is tailored differently by each audience to satisfy its demands, which give rise to specific niche vocabularies and protocols. Beyond the local vocabularies there also emerges a more general ensemble of terminologies and procedures based on the most general principles of the generic device. These are held in common by all users, whatever their specific application requirement may be. Although new-orthodoxy-of-knowledge historians and sociologists are informative about the local aspects of narrow-niche practice, the more profound significance of these practices lies in the residues that become transverse with respect to local contexts. This transverse quality of practice is due more to material demonstration and to concrete practice than it is to the power of rhetoric and professional power, as new orthodoxy proponents would have one believe. Demonstration and concrete practice are in turn grounded on and legitimated by the material and methodological metrologies linked to generic productions.

The shared generic instrument meta-vocabularies, concepts and expectations frequently act as a common basis that enables groups from diverse fields to meet together effectively, where they communicate their difficulties and victories. Cross-boundary encounters are thus frequently grounded on the transverse stock of cognitive and material resources coming out of research-technology programs.

Trans-community cohesion is a consequence. Individuals and groups stretch over their customary restrictive differentiations and boundaries, thanks to the availability of a partially unifying repository of techniques and ideas. It is such cohesion that permits people to move around within science and engineering, albeit often with some difficulty, and into industry or the military and vice versa. Here then, research-technology simultaneously reinforces higher levels of differentiation by helping groups develop specialized tools for local needs, and stimulates higher degrees of integration.

Beyond the cohesion of meeting and communicating, research-technology consolidates doing and knowing. Research-technologies, like micro-processors, cybernetics, automatic switching systems, the

ultra-centrifuge, Fourier transform spectroscopy, broad genetic protocols, liquid scintillation equipment etc., function as multi-level, multi-domain intelligibility devices. The meta-methodologies and meta-artefacts belonging to generic instruments, and which are re-embedded in local, narrow-niche devices, operate like passports. To carry any one of these generic instrument passes permits individuals and groups to transcend their particular realm and to travel into an alternative realm. It is by virtue of this travel and transit that in spite of its several cultures, science sustains a measure of internal community and cognitive cohesion. By the same token, findings initiated in engineering, science, industry, state technical services or the military make sense to neighboring communities, and the results of one field can be viewed as relevant and reliable by practitioners in another field. Because practitioners in one community and intellectual domain perceive that the same generic-based artefact and method as the one on which they ground their particular efforts also works elsewhere, yielding similar results for what are seen as parallel reasons, transverse understandings arise, and transverse confidence is established.

Ian Hacking is correct when he argues that there are sound reasons for belief in a device and in the entities to which the instrument is putatively connected, when one perceives in the course of practice that the apparatus really functions, and that it induces effects and generates results. Rheinberger is equally correct when he stresses, along similar lines, the “enabling” capacity of devices in the course of research, and when he suggests the transcending implications of such enabling operations for collective intellectual achievement.

Successive re-embeddings in different local material contexts and by different groups yield practitioner assurance that the principles of a template apparatus are solid, and that belief in it is well justified. Belief rooted in local experience and testing gradually gains in objectivity. Practices are independently repeated and are multiplied in innumerable environments. This is not the objectivity born of pure reason or the *experimentum crucis*. Objectivization is instead built up through collective practice which is structured around effect-producing materials and procedures. Here, objectivization is cumulative and practical; yet it is never separated from principles or theory.

Communication between institutionally and cognitively differentiated groups of end-users eventually develops. A setting that is

characterized by elements of logic and evaluative procedures arises – logic and evaluation constituting devices necessary to the perpetuation and legitimization of discussion and exchange. Metrology often provides the rules and the language on which exchange is based, and beyond this it constitutes the cement that connects science and technology groups per se to extra-science audiences. In those instances when practitioners perceive that the methodologies, artefacts or theories linked to a generic apparatus do indeed perform for many people in many fields, the upshot is the formulation of a kind of universality. This is a universality born of dis-embedding and endless re-embeddings – the universality of varied experience in countless niches, in sum, a universality grounded in informed and legitimate practice. It is practice-based universality. The weight of trans-personnel conviction, experience and proof coupled to this practice-based universality is then added to the other established tests and procedures more conventionally evoked when science or technology actors think and talk in terms of sweeping generalizations.

It is interesting to consider the research products of the transverse science and technology culture in terms of materials of “pan-validation”. In order for the research outcomes of the transverse science and technology culture to be seen internally as worthy of being sustained, the results have to resonate within a large number of highly diversified environments, some of which are inside science per se, and others outside of science.

Research-technology as a looking-glass

In this final section we examine two questions. First, what differences might the widespread extension of research-technology mean to the dominant science and technology landscape and to relationships with extra-science groups? Second, what additional analytic potentialities would the adoption of the research-technology perspective offer to scholarship in the social studies of science and technology?

In decades to come, research-technology may well emerge as a still more influential and assertive component in artefact and knowledge production. As the world of learning and artefacts becomes more encumbered, complex, and differentiated, transverse mechanisms capable of inducing intellectual order and intelligibility and of

assuring social coherence become increasingly essential. These attributes are a forte of research-technology, as witnessed by its effectiveness in engendering cognitive and material cohesion and practice-based universality. Research-technology may thus come to constitute one weapon in the arsenal against isolated specialization and its corollary of cognitive and social fragmentation. This is not to suggest, however, that research-technology will come to supplant today's historically entrenched institutions. Science and engineering disciplines and academia are century-long stable historical social units. Although they are subject to change, their primacy is not to be denied. Indeed, these benchmarks of learning and societal order are not the enemy of research-technology. Nor are they to be seen as predecessors that must some day give way to it and other new intellectual and organizational forms and modes. The trans-institutionality, mobility and fluidities of research-technology are not to be confused with the New Production of Knowledge and Mode 2 (Gibbons et al., 1994). Indeed, the research-technology concept may be regarded as the antithesis of Mode 2 speculation! The maintenance of erstwhile institutions and differentiations is part and parcel of research-technology's mode of operation and *raison d'être*. Without them, there would be no research-technology, as one of the movement's key attributes is to act as an "in-between" current – an interstitial arena in the midst of well grounded and well defined intellectual, technical and institutional points of reference.

Regarding now our second query, the position of research-technology with reference to the past/future of the social studies of science and technology, there is growing agreement on the need to develop conceptual frameworks and methodologies that can detect and account for inter-institutional collective moving targets. This important objective has not been achieved.

At one end of the spectrum, scholars who mainly ground their studies of science and technology, and the relationships between society and science, on the desiderata of intellectual, professional and institutional demarcations (disciplines, employers, careers etc.) have often been ill prepared to deal with the more amorphous and transformative forms of cognitive and social interaction. Through emphasizing boundary building and maintenance, these features automatically became paramount. Their representation, and the roles and status accorded to them, were sometimes overdrawn.

One thing is certain, heavy reliance on the demarcation analytic model blunted sensitivity to movements characterized by intermittent career oscillations and by cognitive and technical gymnastics.

At the opposite end of the spectrum, the analytic models proposed by proponents of the new orthodoxy school in the sociology of knowledge pose a different but equally acute problem. This radical anti-differentiation stance has blurred the fine yet decisive distinctions that occur between diverse groups, along with their specific goals and procedures. This approach has frequently masked how diverse forms and levels of knowledge and artefacts operate and interact. By seeing science and technologies as a smooth and continuous technoscience, subtlety and nuance are unfortunately lost. All actors and actions appear to be the same, or relatively similar to one another. Research-technology is scarcely visible to this approach, which cannot identify and deal with the constant switching between dis-embeddings and re-embeddings by research-technology practitioners. Nor can it effectively cope with practitioner movement within the complex and highly heterogeneous interstitial arena, where at each instant practice is delineated by a constant commitment to genericity.

The strength of the research-technology perspective lies in three quarters. We want to argue that research-technology is capable of identifying the barely perceptible, delicate balance that exists between uncompromising commitment to cognitive, artefact and institutional stability (for example, genericity) on the one hand, and on the other hand practitioner involvement in acute mobility (for example, controlled boundary crossing within the confines of interstitiality). This bi-directional movement between the center and peripheries, and in a parallel movement between dis-embeddings and re-embeddings, may appear to be a contradiction. Yet it comprises the carefully documented historical and contemporary reality of research-technology practice. It is indeed precisely the fact that the research-technology model offers the possibility of sustaining and appreciating the paradoxical fine structures of cognitive, material and social multi-directionalities that makes this model interesting and of potential utility.

The research-technology perspective similarly provides a basis for a sociological appreciation of cognitive and social cohesion inside and between science and technology, as well as between science and society, that amply takes into account the stuff of

local variations. Because generic artefacts, methods, and procedures possess generalizable, open-ended features, whose generalizations are expressed slightly differently in specific contexts, a shared lexicon of experience and confidence slowly emerges. This lexicon (and not power) comprises the groundwork for pan-validation across disciplines, institutions and nations.

Lastly, the research-technology perspective suggests a new way of seeing divisions of cognitive and social labor. The division of labor has hitherto been regarded by sociology as relatively static, and has been used as a key device for defining and establishing institutional, professional and group boundaries. Research-technology, by contrast, recognizes the dynamic and plastic dimensions of the division of labor. In the research-technology approach, the division of labor continues to act as a mechanism of differentiation. But this perspective also suggests that the division of labor is played out in different ways during different phases of a work cycle. Hence, while at one moment the division of labor serves functions of cognitive or group differentiation, at alternative moments the division is softened or suspended. Here, boundary-crossing becomes more feasible. This malleability in the division of labor lies at the heart of transverse communication as well as pragmatic-universality. Thanks to this emphasis on its dynamic and plastic features, the workings of division of labor in science and elsewhere may now be studied in a new light.

Terry Shinn is director of research at the CNRS (Centre National de la Recherche Scientifique) and is based at the Paris Maison des Sciences de l'Homme. He is the co-editor (along with Bernward Joerges) of *Instrumentation between Science, State and Industry* (2001). Shinn has also published abundantly on topics related to science and technology education, university–industry relations, and the intellectual and social organization of research laboratories. *Author's address:* GEMAS, CNRS, Maison des Sciences de l'Homme, 54 Bd Raspail, Paris 75006, France. [email: shinn@msh-paris.fr]

Bernward Joerges is a researcher at the Wissenschaftszentrum Berlin für Sozialforschung (WZB) where he heads the Metropolitan Studies Group. He is also professor of sociology at the Technische Universität Berlin. He has published widely in German, English and French in the fields of science, technology and urban studies. Book publications include *Technik ohne Grenzen* (1994), *Technik – Körper der Gesellschaft* (1996), and *KörperTechnik: Aufsätze zur Organtransplantation* (1997). *Author's address:* Wissenschaftszentrum für Sozialforschung Berlin, Reichpietschuger 50, 10785 Berlin, Germany. [email: joerges@medea.wz-berlin.de]

Note

1. The proceedings of the *Deutsche Gesellschaft für Mechanik und Optik* monthly meetings appear systematically in the *Zeitschrift für Instrumentenkunde*.

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