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Sources of Intellectual and Social Change

A Fresh Perspective

Academic and public debate of recent decades has seen an important transformation in thinking about the sources of change in scientific knowledge and material innovation. Prior to about 1980 fundamental research in science was held to constitute the fount of both academic advance and industrial progress. Science drove technology, which was in turn seen as fuelling innovation. Technology here comprised an outgrowth of scientific research. In later decades presuppositions regarding relations between science and technology have become more complex, and have indeed in some analyses become reversed.

The concept of "technoscience" conflates science and technology, which are represented as indissociable and interdependent (Hottois 1984, 2006). Such technoscience takes a variety of forms. In some circles it is portrayed as a rapprochement between technology and science through the penetration of advanced complex instrumentation in science so that science is now synonymous with technology (Latour 1987). Technoscience is alternatively represented as the exploration by science of artefacts and dynamics resulting principally from technology as opposed to the study of "natural", technologically independent bodies or processes (Klein 2005). The role played by technology in culture and its relative hierarchic position is also central to postmodern discourse. Postmodernists (Forman 2007) argue that technology today supersedes science as a cultural, intellectual and material force. The erstwhile hierarchy between science and technology is here reversed. Technology is similarly viewed as spurring academic scientific learning, rather than the other way around. Technology has thus emerged as the foundation of cognition and material change.

Ancient and extant views of relations between science and technology share an important point in common. Both project an often crude and one dimensional representation of the two activities – a form of simplified science versus a simplified representation of technology, vice versa, or a simplified "Hegelian" synthesis between science and technology. Technology and science, and above all the relation between them and with culture, is clearly far subtler. It is today urgent to identify and distinguish between more refined categories of technology, to locate the emergence of specific clusters linked to particular historical conditions, and to ascertain on this basis the variety of ways in which technology, science and culture interact. Such an understanding is a precondition to a deeper grasp of cultural dynamics and change.

This book identifies and explores a form of technology that is absent from past discussions of knowledge and artefacts. We term this form of technology "research-technology" a mode of material and intellectual work, organisation and communication which first arose in the late 19th century and which continues to flourish today. Examples of successful research-technologies include automatic switching systems, the ultracentrifuge, the laser, cybernetics, Fourier transform spectroscopy, the Cooley–Tukey algorithm, the C++ multipurpose object oriented computer language, the scanning tunnelling microscope, etc. In conventional parlance, the analytic language used by sociologists and historians of science and technology often draws a distinction between technology and academic learning. The world of research-technology, we suggest, bridges the two. The bridging occurs with respect to knowledge, skills, artefacts, language and imagery, and their attendant interactions. In a research-technology frame, conventional oppositions such as theoretical and experimental, science or engineering, technology and industry are largely effaced. The focus is neither on scientific practices, in the sense of theorising about experimentally produced phenomena, nor on engineering practices, in the sense of constructing and producing definite end-user goods and services. Instead, the focus is on practices oriented toward the production and theorising of open devices, which potentially serve multiple spheres.

The research-technology perspective raises issues in three problem domains. Firstly, how can the research-technology phenomenon be situated with respect to the ongoing debate about the dynamic relationships of science and society? Secondly, how can it be situated with respect to a gradual scientisation and increased occupational fluidity of engineering professions, which characterises the changing relationships between science and engineering? Thirdly, how can it be situated in the contemporary debates in philosophy and social studies of science over the relationships between theory and experiment? This introductory chapter will briefly address each of these points.

Science and Society

The theme of "instrumentation between science, state and industry" does not square well with the venerable discourse which opposes "science" and "technology" in social studies of science. In this discourse, "technology" stands for the contrary of "science"; it represents the practical uses of science in society at large and is understood as separate from the somehow autonomous sphere of "science" (Layton 1971a). This vocabulary, widespread as it may be, is not very useful for our purposes, and, for that matter, for any inquiry into the role of instruments. Technology, in the sense of technical instruments and the knowledge systems that go with them, pervades all societal systems. There are technologies of science, of industry, of state, and so forth, and it would be ill-advised to assume that, in the end, they all flow out of "science." But even if the crude opposition of science and technology has little analytic value, the dual problem remains: how to effectively conceive the dynamic relationship between scientific spheres and other societal spheres, and how to conceive the role that technological matters play in this relationship.

Much of the debate surrounding these issues is framed in terms of "What drives what?" Does science drive technology (that is production technology, the field of utilitarian technology aimed at producing things for use outside science) or does technology drive science? Using "industry" and "state" as we do in this book as shorthand for extra-scientific social spheres, this translates into the question: Do science and its technologies drive those of industry and the state, or is it the other way around?

Schematically speaking, the relationship can take four forms: science drives industry/the state; industry/the state drives science; the relationship is independent; or it is dialectical. In terms of ideal types, these four positions have all had their protagonists. The current fashion seems to be a special version of the dialectical answer where science and industry/the state are inextricably interrelated (e.g. Latour 1992). In extreme formulations, the science/technology nexus has become a hybrid field of seamless webs where the distinction between them is no longer considered useful. According to this view, there is only technoscience, in which the boundaries between science and industry/the state are discursive artefacts that must be looked at in terms of their strategic utility. Moreover, these boundaries are in constant flux depending on the interests of dominant players.

The research-technology perspective does not accord with seamless analytical frames of this kind. We will argue that research-technology instrumentation is a phenomenon "in the middle" which does not coincide with either science or industrial production. We see it as a field of instrumentation outside both science and industry, yet important for both.

It is possible then to distinguish three spheres of instrumentation and instrument-makers: inside science, as in conventional studies of scientific instrumentation (Heidelberger and Steinle 1998; Heilbron, van Helden, and Hankins 1992; Löwy and Gaudillière 1998); inside industrial production, as in conventional studies of nonscientific technology, such as the assembly line (Noble 1984); and outside science and production, but for both. This third type belongs to research-technology. In other words, we wish to bypass one erstwhile notion whereby instrumentation in science and technology has two distinctly different sources, and another erstwhile notion whereby technology is an applied side of science.

The strong thesis that guides the analysis presented in this book is that research-technology generates broad fundamental impulses that drive scientific research, industrial production and technology-related state activities along their respective paths. Of course, the research-technology hypothesis does not deny that much instrumentation is conceived, developed and diffused within the strict confines of a narrow industrial (von Hippel 1988) or scientific (Edge and Mulkay 1976) context, nor does it imply that research-technology mechanisms account for all types of transfer from one sphere to another.

Science and Engineering

To better understand the emergence of research-technology, it is useful to see it against broad transformations in engineering practice and institutions. Historically, the knowledge base and professional practices of engineers in many fields have changed appreciably as technology has become ever more scientised. In the past, engineering was often associated with practical craft skills and with the application of technical recipes to concrete problems. Since at least the Second World War, the intellectual and professional gap that separated science and engineering has gradually diminished. Emblematic of this rapprochement is the increasing use of the terms "engineering science" in the Anglo-American world, "Ingenieurwissenschaften" in German-speaking countries and "science physique pour l'ingénieur" in France.

The professional identity of engineering groups in civil engineering, mechanics, chemistry, electricity and electronics often entailed a demarcation from mathematised esoteric learning and disciplinary academic science, as well as a demarcation from the university departments that taught and researched such learning. While engineers trained in university schools of engineering, in many important respects they nevertheless stood outside of academia. Engineers' principal intellectual and professional identity instead lay with their industrial employers. Professional engineers generally centred their careers in non-academic organisations, where they usually remained (Layton 1971b). This traditional profile has changed appreciably, however. Today, engineering knowledge and practice increasingly bear the mark of high science as, in turn, academic disciplines depend increasingly on scientised engineering (Bucciarelli 1994).

The scientisation of engineering is associated with growing cognitive specialisation. New fields of academic learning have emerged, and many of them are directly relevant to engineering. Mastery of these fields by engineers often entails a grasp of advanced mathematics, as well as a firm grounding in academic science. Concurrently, many technical systems have become ever more complicated and large-scale, thereby requiring additional learning and skills. Beyond this, the scientisation of engineering has involved significant professional changes. Engineers had long been envious of the lustre of science and the high social status of scientists. The emerging links between engineering and academia have provided engineering professions with an opportunity to share the elevated status of academic learning. Also, scientised engineering involves enhanced career fluidity. Engendered by fast-moving technical frontiers, many practitioners move from project to project.

The last few years have seen the rise of two analytic schemata that focus on a convergence between scientists and engineers. In *The New Production of Knowledge,* Gibbons and his colleagues have suggested that the development of new knowledge-intensive economic spheres is accelerating the de-differentiation between scientists and engineers, and is producing a new category of cognitive and technical personnel whose point of reference is the solution of socially relevant problems (Gibbons *et al.* 1994). The Triple Helix perspective similarly hypothesises a radical convergence between scientists and engineers—a convergence which putatively yields a historically new intellectual and technical breed expressed as a synthesis of the two professional groups (Etzkowitz and Leydesdorff 2000, 109–23; Leydesdorff and Etzkowitz 1998). This synthesis does not, however, take the form of a de-differentiation but instead a neo-differentiation (Shinn 1999). At first glance, research-technology might appear to belong to the New Production of Knowledge or Triple Helix schemata. However, it has to be established whether the kind of fluidity we associate with research-technology is of the same sort described in these two perspectives, particularly as regards the intellectual and social work connected with instrumentation.

Theory and Experiment

With few exceptions, students of science have long considered that experimentation was paramount in scientific research. Experimentation was seen as guiding theory, or even as governing it. This stance is reflected in many of the classical studies on Newton, Galileo, and Huygens, and it underpinned the work of philosophers in the logical positivist tradition (Suppe 1974; Westfall 1980). Pierre Duhem was among the first to question the dominance of experimental orthodoxy, and Kuhn successfully extended Duhem's thesis (Duhem 1915; Kuhn 1962). The relationship between theory and experimentation continues to be reassessed, and today many scholars believe that theory often guides, and even dictates experiments and their outcome (Bachelard 1951; Pickering 1984; Pinch 1986; Quine 1972, 1986).

Nevertheless, a handful of historians and sociologists question whether the relationship between theory and experimentation is as direct and unmediated as it is often made out to be. Peter Galison, for example, has argued that the old debate about the interplay of experiment and theory, and the attendant ideological debates about the epistemological correctness of idealist and empiricist positions, needs to be revised by introducing a third dimension; namely, instruments and the theories attached to them (Galison 1997). Galison does not suggest that instrumentation provides a panacea for establishing the validity of a knowledge claim; he instead indicates that instruments constitute a third reference against which statements can be tested, and are a semi-autonomous input into both experimentation and theory. Nevertheless, his approach also focuses predominately on the role of instrumentation inside science proper. It is a debate about science and technology in the procrustean framework of technology in and of science. In recent decades an additional referent has penetrated science, namely models. Models are sometimes linked to the technology of numerical simulation, and in this guise fall into the category of experimentation (Kuipers, Lenhardt and Shinn 2006). It is increasingly asked if simulation-based modelling comprises a new form of experimentation, and if so, whether what constitutes experiments and what counts as validating proof thus require fundamental rethinking. Other observers (Cartwright 1997 and Morgan 2004) associate models with theory, yet carefully and strongly distinguish them from theory. Models, they argue, are kinds of devices (Francoeur 1997) which lie closer to phenomena and to experimental practice. They capture features not effectively portrayed by most theory. They are more malleable and can thus better advance research practice. It is frequently suggested that while theory deals with the structural or dynamical features of phenomena, models instead elucidate more narrowly functional attributes or may operate as maps that prefigure future investigation. Beyond the timely reflection on the structure and role of models and of Galison's influential contribution, one can observe a general renewal of interest in the technical, cognitive-epistemological and socio-cultural aspects of metrological devices throughout the field. How does the research-technology perspective fit into this debate?

In positing that research-technology is a specific kind of instrumentation, one that is explicitly characterised as poly-disciplinary and potentially extra-scientific in its purposes and effects, we confront the theory/experimentation problem from a different angle. It may safely be said that mainstream philosophical and sociological schools in the study of science have generally paid scant attention to boundary-crossing practices and representations of the sort common to research-technology where instrumentation transcends experimentation and the theory/experimentation matrix. This line of inquiry extends recent claims that independently of measuring and representing effects, experimental systems also perform controlling and productive functions for purposes beyond scientific knowledge and theory validation (Hagner and Rheinberger 1998: 355–73; Heidelberger 1998: 71–92).

A SPECIFIC KIND OF INSTRUMENTATION

Against the backdrop of ongoing debates around science/society relationships, theory/experimentation relationships, and changes in engineering practice and institutions, we can now turn our attention to the emergence and workings of research-technology. Three major features of research-technology come to the fore. The first characteristic is its trans-community positioning – otherwise stated, its "interstitiality." Research-technologists wear many hats. Secondly, their devices exhibit a peculiar openness or "generic" quality. Research-technology devices branch out toward many spaces. Thirdly, research-technologies involve the development of standardised languages or "metrologies." Research-technologists create a lingua franca for theoretical and extra-theoretical uses.

The case histories presented in this book explore social interstitiality, generic instrumentality and metrological codification in a variety of trans-disciplinary, trans-science and extra-science settings. What accounts for this configuration and how research-technologies acquire their distinct feature of travel between otherwise unconnected fields? How is it possible that local instrument achievements become global in the sense of a re-embedding in many other places, both inside and outside science?

Interstitial Communities

In what sense can one talk about research-technology communities? The research-technologists who appear in this book, exhibit peculiarly "subterranean" modes of multi-lateral professional and institutional association that do not accord well with standard sociological notions of communities as ensembles of stable, institutionalised interactions. These research-technologists admittedly work within universities, industry, state or independent establishments, yet at the same time they maintain some distance from their organisations. In many instances, they pursue "hybrid careers," shifting back and forth between different employers or, while remaining with a single employer, lend their services to changing outside interests. Many research-technologists develop a personality make-up suited to sustain many-sided professional relationships and "multi-lingual" cognitive worlds.

Some sociologists will say that research-technology's social configurations should not, for these reasons, be called "communities," but rather non-communities, since research-technologists are not concentrated within one type of scientific, industrial or state organisation which provides them with stable, recognised positions reserved for experts in generic precision instrumentation. Indeed, research-technologists' community identity cannot be mapped in terms of an organisational or professional referent. The referents of "academic scientist" or "industrial engineers" are not relevant to research-technology. Neither can the identity of research-technologists be based on the production of a definite category of fact (in science) or artefact (in production). Instead, the shared project that conveys a semblance of community in the familiar sense of the term is their elaboration of diffuse, purposefully unfinished devices (not-yet facts and not-yet artefacts) to be distributed across the broadest possible landscape.

In cases where research-technology involves a shared project for groups of practitioners working within the same field of instrumentation, the term community, in the classical sociological sense, will be acceptable to most analysts. In other cases though, "shared project" merely means that research-technologists recognise each other's pursuits when they happen to meet. The term research-technology community refers here to something akin to the way tribesmen know they belong to the same tribe. In order to avoid confusion with other tribes, various insider/outsider affiliations are invoked. Rather than by tracing stable membership and hierarchical/promotional career structures, research-technologists can more easily be identified through specialised academic or trade journals and by their participation in national or international instrument fairs and expositions. Historically, instrument fairs have played a major role in the constitution of the research-technology movement.

In connection with interstitiality we need to understand how research-technologists avoid standard forms of professionalisation. What are the sources of their open and flexible group identities? Their interest as a class of experts seems to lie in expanding the sphere of unaffiliated, open-to-all, dispersed generation of devices that promise solutions to problems where precision detection and measurement, precision control of certain phenomena and even the controlled production of certain effects are crucial for success. How do research-technologists manage to articulate and defend group interests in the absence of membership organisations with established boundaries? Separate as research-technology groups are from both conventional science and industrial engineering, yet parasitic on both, how do these quasi-communities assure community reproduction and growth? How do they sustain their autonomy in environments that have customarily rewarded monopolistic organisational linkages?

Generic Devices

We refer to the particular kind of technical artefacts research-technologists deal with as "generic devices." Research-technology communities first arose in the 19th century with precision mechanics and optics and today specialise in the invention, construction and diffusion of precision instrumentation for use both inside and outside academia. They develop packages or whole systems of generic detection, measurement, and control devices that focus on particular parameters which are potentially of interest to scientists, laboratory technicians, test personnel, production engineers, and planners—as in the case of early lasers and masers, or the case of laboratories producing new semi-conducting materials, research-technologists and their generic devices produce novel physical effects in order to explore their measurability and controllability.

In many instances, these devices are not designed to respond to any specific academic or industrial demand. Research-technologists may sometimes generate promising packets of instrumentation for as yet undefined ends. They may offer technological answers to questions that have hardly been raised. Research-technologists' instruments are then generic in the sense that they are base-line apparatus which can subsequently be transformed by engineers into products tailored to specific economic ends or adapted by experimenters to further cognitive ends in academic research. Flexibility is part of the product. One could say that "interpretive flexibility" constitutes itself as a goal and an achievement. This is a precondition for research-technology's extended market that stretches from academia to industry and the state.

Research-technologists are typically involved in prototyping, in the sense that they avoid closure of design processes that keeps devices generic. In connection with genericity we need to understand how research-technologists manage to maintain an instrument chain in which "core devices" are developed, that then spawn cascades of secondary apparatus, which are in turn used to solve a range of problems. How do generic devices make their way into both research and production?

Metrology

Metrologies can be seen as systems of notation, modelling and representation, including their epistemic justifications. Metrology is integral to the development of generic devices and the maintenance of interstitiality. Either the nomenclatures, units of measurement and standards of existing metrologies are refashioned in creating generic instrumentation, or else new ones are formulated. The lingua franca of metrology constitutes the vehicle that allows generic apparatus access to many audiences and arenas. At the same time, it preserves research-technologists from becoming caught up in the particular discourses of these audiences and arenas.

On one level, research-technologists may generate novel ways of representing, visually or otherwise, events and empirical phenomena. On a broader level, they may impose a novel view of the world by dint of establishing and legitimating new functional relations between recognised categories of elements that were previously perceived in a different light. In some cases, research-technologists' metrological work is instrumental in coalescing and crystallising notations, analytic units and formulas into a corpus of rules or procedures which deserve to be called a methodology, and that eventually make their way into textbooks as state-of-the-art procedures. How is this achieved?

Ultimately, the issue of metrology includes questions concerning the particular epistemological stances, and even world views, associated with research-technology work. Do research-technologists sometimes even stylise and theorise their own procedures in a manner that deserves to be called the advancing of a world view or episteme? (An example is the sweeping and comprehensive views of cyberneticists who see nature as a grandiose engineering feat, see Heims 1991.)

Dis-embedding, Re-embedding

One way of drawing together considerations of the institutional, instrument and metrological aspects of research-technology processes is to look at them in terms of an iteration of dis-embedding and re-embedding episodes in the far-flung trajectories of a particular device or prototype. Recent approaches in the philosophy and sociology of science and technology have consistently pointed to the situatedness, localness and embeddedness of all knowledge production. Arguments about instruments are at the core of these positions, whether they are framed in terms of tacit knowledge, craft, the bodies of experimenters, or science vernaculars (including Pidgin and Creole). At the same time, claims about universal standards of rationality in experimentation and engineering tend to be presented as mere representations or legitimations of scientific and technological practice.

In contrast, research-technology, as a distinctive mode of producing instrumentation for de-situated and trans-local uses both inside and outside science, appears as a distinct achievement of dis-embedding which lies outside the purview of such approaches. In this perspective, dis-embedding does not occur by default, as in diffusion theories, but is instead tied to specific skills and forms of representation. While admittedly all knowledge production, including instrument knowledge, is local, and all knowledge consumption is local too, the central question remains: how can knowledge be consumed far from its place of production, and how does it travel?

We suggest that generic instruments comprise a sort of dictionary that enables the translation of local practices and knowledge into diverging and multiple sites, and constitutes the transverse action of research-technology. Can something akin to universality arise through the sharing of common skills and representational systems located in a device like a template, or "hub matrix?" Could one say that research-technologists design dis-embedded generic devices so that they can be readily re-embedded? Local re-embedding by engineers or scientists occurs within the limitations contained in the template of the generic instrument and also within the limitation of the local cultural and material context. Re-embeddings can thus differ considerably from one another, yet a certain fidelity to the hub template persists. To what extent does the use of a specific template by practitioners in different localities allow them to communicate effectively through the development of converging skills, terminologies and imagery? It may be this feature that makes research-technology the potent, universalising motor that we take it to be.

The instrument-related phenomena dealt with in this book may be seen as new in the sense that they have become more varied and broadly visible since World War II, yet it would be inappropriate to see research-technology as something radically new. Also, while research-technology may eventually increase in size and scope, this does not indicate that it is a new form of science. Instead, research-technology is a new perspective, an alternative way of looking at instrumentation for social studies of science and technology. Since it is very much a phenomenon "in-between" and often relatively invisible to outside observers, it is not surprising that it has gone largely unnoticed by students of science and technology.

The five studies presented in this volume explore the circumstances under which research-technology fields have emerged and evolved in light of changing demand inside and outside science. Chapters deal with the places, times, and technological fields where research-technology occurs. They present the institutions, journals, meetings, forms of association, and the multi-professional and multi-personal identities that sustain research-technologies. The concluding chapter will situate research-technology in the landscape of social studies of science and technology and reflect on some of the broader societal corollaries of the research-technology movement.