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Invisible Connections: Instruments, Institutions, and Science, edited by Robert Bud,
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Part III National Concerns

Introduction

The role of instruments in the development of science was once strangely invisible. Now, however, in two separate spheres of activity, instruments have become the focus of attention. In science policy, the increasing cost of research, driven especially by skyrocketing costs for its capital base, has prompted questions about spending on instruments: How much is enough? How should instruments be distributed among research organizations? Should central governments intervene, or should all decisions be left to institutions? At what point do shared instruments become cost effective?[1] Meanwhile, as part of the effort to correct an earlier over-emphasis on theory as a driving force in scientific change, historians, philosophers and sociologists of science have taken a new interest in the experimental process.[2] The history and sociology of science is already establishing a canon incorporating studies of modern research as well as seventeenth-century science. The potential for links with the policy debate has become clear, for the two lines of questions share a concern with the relationship between scientific instruments and the political and economic context of science. Yet the two traditions still have much to learn, and to contribute, from greater familiarity with each other's problems.

This volume presents papers first discussed at a 1991 workshop held in London's Science Museum, intended to explore the areas of common interest. The contributors include science policy analysts from the USA, France, Canada and Britain, as well as sociologists, historians, and practicing scientists in the forefront of NMR techniques. Individually the contributions join other recent work in drawing attention to instruments in the laboratory, particularly breaking new ground in the perspective they provide on industrial innovation. Together, the papers are intended as a step in bringing instruments back into coherent view, for policy makers and for those who analyze science.

The papers have been organized according to three broad themes. The first set explores the complex interaction between laboratory and industrial instruments, and the parallels between industrial organization and the organization of the scientific workplace as revealed through constellations of equipment. Next, a set of modern case studies introduces important concepts in the analysis of instruments in context: standardization, differentiation, and diffusion, among others. A final group of papers describes the emergence of large-scale and middle-range instruments as a problem in national science policies, along with recent attempts to address those problems. This introduction points to cross-cutting themes.

Each section is also prefaced by editorial comments intended to highlight local themes and issues. The interface between the variety of disciplines represented in this volume is too complex and dynamic to enable a definitive overview. However, three major issues are highlighted by the papers represented here. The reader will be constantly reminded of the tension between instruments as malleable experimental devices and as objects of consumption; their pivotal role between the cultures and economies of science, on the one hand, and, on the other, of much broader industrial markets; and of the number of issues fused within the "need" for an instrument.

1. The Scientific Workplace

Historians of scientific instruments have all too often reserved their analysis for the nineteenth century and earlier. By contrast, the authors of this book concentrate upon the twentieth century. They describe an independent realm of instrument innovation and diffusion, a realm which intersects fruitfully and often with other realms of technological innovation to exert a steady and significant force for change in scientific ideas. This is the practical importance of instruments, which form the material basis of laboratory life. They have, too, a cultural significance: their perceived role in science has been closely allied with an increasingly technological vision of the future.

While the authors use the term instrument comfortably, they make no naive assumption that they are dealing with simple, easily-bounded phenomena when they do so. Instrument systems are internally heterogeneous, as exemplified by Gökalp et al.'s description of laser Doppler anemometry, an experimental approach that combines several optical and electronic technologies. Furthermore, any instrument merges in practice with procedures and techniques, both practical and theoretical. Indeed, these authors claim, instruments and theories have more in common than the usual descriptions indicate. Theoretical techniques, like instruments, must be worked into new contexts through craft knowledge and local adaptation; take for example the diffusion of the Fourier transform.

The local adaptation of instruments emerges from these papers as a prominent feature. Edge's description of mosaic arrays in infrared astronomy both illustrates and explains this phenomenon. On the one hand, the mosaic arrays are differentiated by local circumstances—sociologists would call them contingencies. But they are also differentiated through the pattern of competition in the field; each team needs to find its "niche" and tunes its instrument to that task. As a result, the configuration of skills and instruments in a laboratory becomes what Mukerji calls a laboratory "signature". These factors push scientific instruments toward a state of "smallest possible market"— each laboratory's needs being ever-so-slightly different from the next's.

This differentiation is intrinsic to their role. Instruments provide for exploration and play in the experimental sciences. They allow scientists to explore tentatively at the edge of what is known, without the constraints of deductive theorizing. Mukerji's paper posits a parallel between ocean scientists and children, both of whom playfully push the limits of what their peer groups know. Both use tools to do this, although the oceanographers often find theirs in the tool chests of their military sponsors rather than the toy chests of the nursery.

Conspicuous consumption is a counterforce to the process of differentiation. Laboratory equipment is more than functional; it is also an important element in the power and prestige of its owners. This factor can set in motion a wave of diffusion of a standard instrument, whether or not it will be efficiently used. Blume points to such a pattern in hospital technologies, but laboratories are unlikely to be immune from the syndrome.

Several of these authors (Blume, Rabkin) claim that instrumentation is becoming more standardized—that the spread of black box equipment overshadows the pattern of differentiation. Blume goes further in claiming that the trend toward standardization takes its force from a long-term shift in work organization in the sciences. Mendelsohn's arguments, however, lead to the opposite conclusion. He calls attention to the increasing scale of instrumentation in science, a factor which can only lead to more unique instruments and fewer standard ones. The true balance between the differentiating forces of competition and the homogenizing forces of conspicuous consumption is of course a matter for empirical investigation: both patterns are theoretically plausible, and have actually been observed.

2. Markets and Innovation

The authors in this volume share the assumption that instruments, as technologies, are not disconnected from the larger worlds of consumer and industrial technology, even though as a market, science is dwarfed in size by those worlds.

First, techniques diffuse across the boundaries of industrial and scientific technologies, and spark new combinations in both areas. Research can change the technical basis of the technologies that address a certain practical problem, as in the second wave of NMR innovation (see Feeney and Morris). Likewise, new technologies can radically alter the access of a community of scientists to its phenomenon of study. Throughout, the book provides examples of technological innovation stimulating scientific change, with technological needs often calling forth scientific efforts. Feeney's description of the research that went into the second wave of NMR development again illustrates just such a process. Edge describes how the mosaic array allowed infrared astronomers new levels of data acquisition; and the laser Doppler velocimeter, which had no antecedent equivalent, opened a whole new window on the process of combustion.

As with many types of technological innovation, the cases reported here show that people are an important element in spanning the institutional boundaries between the laboratory and the industrial firm. Scientists clearly do get involved in the development of instruments, in particular because of their ability to merge scientific and technical aims in the process of scientific work. Instrument makers, likewise, do interact with the laboratory as they develop and refine new products.

Because of the close historic connection between science and the military, and the constant level of technological change in modern warfare, the military has been a major supplier of new technologies for science. Mukerji's descriptions of oceanographers suggest how unlikely it is, in a military-dominated science, that change would flow from science into technology. Her example, and indeed the military market, is not unique. Thus several authors describe how techniques developed for other purposes first dribble into science, and then scientists scramble to individualize them for competitive purposes.

This perspective raises important questions for policy. Is innovation through instruments a major contribution of science to technology, or not? Is it increasing or decreasing? Which set of forces is stronger—those for standardization, or those for tinkering and differentiation?

3. Needs

The central science policy interest in instruments has been how to respond to scientists' calls for expenditure. This volume examines the pressure as a phenomenon to be measured, evaluated and examined critically. Some authors take off from the vision that informs contemporary science policy. A new instrument is equivalent to a major but passive scientific resource. The advance of science demands them. If policymakers fail to provide adequate resources to supply this need, they risk both losing out in the competition between scientific nations and violating the technological imperative of progress. The papers by Stine and Kruytbosch chronicle the emergence of this viewpoint, which dominates policy discussions in all industrialized nations today. Georghiou and Rocher illustrate the resulting efforts to gather data on instrument stock and flow.

Policy makers have taken scientific needs as given; however, they are a complex category. Their relations to instrumentation are explored by other papers which question the assumption that scientific advance, defined without reference to its content, is an adequate definition of the goal of policy. The authors examine the process of choice among goals, and therefore explore the question, "What kind of scientific progress is being provided?" The cost of instrument-driven scientific developments can itself carry overtones of importance; and it can sometimes seem that the reductionism implicit in experimental control produces more valuable knowledge than the study of emergent properties of complex systems.

The history of accelerators (Krige tells part of it in this volume) illustrates the relationships particularly clearly. As his story shows, the emergence of an accelerator takes place in a context of scientific and national competition. The community of high energy physics is up against nature in its demand for higher energy ranges for their accelerators; but it only takes one machine to meet this "need". There have been numerous proposals, however, to build a World Accelerator, but they have never been implemented. Why? One workshop participant observed that "if there were a World Accelerator, there would be no high energy physics". He implies that the connection between technology-based science and national pride is not just a peripheral factor; it is constitutive of the science itself. Would that we could see that element of our own culture as clearly as Simon Schaffer helps us see the values of Victorian England in the development of metrology.

In conclusion, the papers in this volume richly illustrate how scientific instruments can be looked at together, by scientists, specialist policy makers and academic science studies communities. If their interests remain distinct, this volume suggests they have much to share.

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[1] The literature relating to policy makers' concerns has been largely in the form of reports. The contributions of Georghiou, Kruytbosch, and Stine to this volume bring together much of this literature.

[2] As recently as 1985, a distinguished historian of chemical instrumentation, Robert Anderson, could write "Historians of science have paid relatively little attention to scientific instruments and apparatus over the past twenty years. Chemical apparatus has fared particularly badly, and it is difficult to think of a single major contribution over this period." Robert Anderson, "Instruments and Apparatus," in Recent Developments in the History of Chemistry, ed. Colin A. Russell, London: Royal Society of Chemistry, 1985. Since then, social historians have been interested in the ways facts and achievements have come to be established and the nature of experiment. Works which have proved particularly stimulating include Steven Shapin and Simon Schaffer, Leviathan and the Air Pump: Hobbes, Boyle and the Experimental Life, Princeton: Princeton University Press, 1985; and Peter Galison, How Experiments End, Chicago: University of Chicago Press, 1987. The ways in which the process of measurement in a technological context can be opened up are demonstrated by Donald Mackenzie, Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance, Cambridge, Massachusetts: MIT University Press, 1990; and the development of technological measurement techniques has been recounted by Stuart Bennett, for instance in his A History of Control Engineering, 1800-1930, Stevenage: Peter Peregrinus, 1979. Many recent contributions have been made through conference proceedings such as David Gooding, Trevor Pinch and Simon Schaffer, eds., The Uses of Experiment: Studies in the Natural Sciences, Cambridge: Cambridge University Press, 1989; and Frank A. J. L. James ed., The Development of the Laboratory: Essays on the Place of Experiment in Industrial Civilization, Basingstoke, Hampshire: Macmillan, 1989. The generally more detailed approach taken by papers read to the Scientific Instruments Commission of the International Union of History and Philosophy of Science is represented by Christine Blondel, Françoise Parot, Anthony Turner and Mari Williams, eds., Studies in the History of Scientific Instruments, London: Roger Turner Books Ltd., 1989. The interests of scientists in their work is expressed in such work as Carol L. Moberg, The Beckmann Symposium on Biomedical Instrumentation, New York: Rockefeller University, 1986.