How Experiments End. PETER GALISON. Chicago: University of Chicago Press, 1987. xii + 330 p. Cloth $39.95, paper $15.95.

Peter Galison is in the philosophy and physics departments at Stanford University, and in its program for the history of science. His book tells how high energy physics changed from desktop devices into "big science." His three deeply researched central chapters of case histories (pp. 21–241) will form one of the classical accounts of that epoch, but the last two chapters of the book are a contribution to epistemology. I shall briefly mention a few of their lessons, warning that I shall be giving one philosopher's heightening of Galison's more cautious exposition.

1. *The title* is significant: How *do* experiments end? That includes the question of what makes a body of data compelling grounds for settling an issue? The question has long been central to empiricist attitudes to knowledge, but it has seldom been asked so cleanly. Of course, most experiments that do not end in disarray end by being salvaged: the workers get enough to continue their careers. But what about those which end by finding out something people want to know, and which become benchmarks for future enquiry? It is these, so we are taught by most philosophies, which are among the foundations of scientific knowledge. Experiments end in consequence of interactions among a small number of people, the instruments that they construct, and something to which they apply their apparatus. Hans Reichenbach called that the context of discovery; the results of an experiment were, however, evidence that provides a logical and ahistorical justification for some conclusions. A decade ago, "social construction of scientific facts" philosophers implied that there is no such distinction between justification and discovery, and that evidence is a social product; experiments end when people have worked out their differences. Galison is neither Reichenbachian nor constructionalist. He denies that evidence has a purely logical content used in justification. Not only are data produced in material circumstances, but what counts as evidence is the product of historical traditions of experimentation and instrumentation. But there are strong nonsocial determinants of inquiry. Galison aims at characterizing these constraints.

2. *Instrumental traditions:* "Instruments have a life of their own." Experimental and instrumental traditions may be largely independent of higher level theory—a big change in our beliefs about the world may leave many of the instruments intact, and there can be radical innovation in apparatus not connected with a scientific revo-

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lution. What counts as answering a question, and hence what serves to bring experiments to an end, will differ between traditions. In nuclear physics, one tradition counted events in the aggregate (and hence built machines that made myriad events and counted them), while another produced visual displays of single events. The one sought a compelling array of data en masse (and what makes it compelling is part of another tradition, namely, that of statistical analysis). The other wanted the visual presentation of a "golden event" convincingly (and literally) demonstrating what is true. These are fundamentally different conceptions of evidence. The elaboration of one kind of apparatus produces new conceptions of what counts as evidence; the idea of "evidence" and the physical means to produce it are constantly modified. "Evidence" ceases to be a purely logical concept, arbiter of what it is reasonable to believe. Data have status only within a set of practices engineered to produce them.

3. *Experimental structure:* Galison cites Clerk Maxwell on scientific apparatus (1876). The greatest theoretician/experimenter of the nineteenth century was no slouch at philosophical analysis. He showed how the experimenter isolates the apparatus from "disturbing agents" and creates phenomena that do not occur in nature until people have separated them from the prehuman course of events. He thought one did this by controlled transfers of energy, and he had a tidy classification, with three main heads, of the functions of an instrument: (1) a source of energy, (2) a transporter of energy, and (3) a measurer of the effects of the energy. This captures presciently much of the most celebrated experimental physics of the twentieth century, with one exception. The experimenter once related to theory through the apparatus and the results recorded in (3), processed in a minimal way. Then you could see what it all "meant." Increasingly we now add (4), procedures for analyzing, processing, and communicating data, procedures radically transformed by fast computation, not just at the level of sums, but also, for the visual tradition, by scanning and image enhancement. It is a commonplace to say that we live in the computer age, but no one has so succinctly argued that this modifies the structure of an experiment, not just by adding a new layer of workers, but by changing the very objects that count as the "data" for theoretical analysis.

4. *Scale:* Does it matter to epistemolology? Page-long lists of authors of a single paper grab attention. High cost determines bureaucratic review procedures for funding. There is a division of labor, with designers of detectors in a high-energy project being a different class of people—and using different physics—from designers of energy sources. There are echelons of industrial managers and safety

engineers, as well as the aforementioned data processors. Does this have any effect on scientific method and inference? Galison suggests that particular traditions of experimentation become much more rigid. With a hand-made desk-top device it was easy to modify any part of the instrument, to change it in significant ways when one revised one's idea of how the thing works. But the vast investment of big science in industrial plants—with a very small number of employees, despite the growth in number of Ph.D. physicists and their support staff—preselects admissible interfaces with phenomena. The class of possible data is settled by styles of instrumentation and by existing apparatus to a greater extent than science ever knew before. Big science builds into itself certain conceptions of the world and is almost "revolution-proof."

5. *Constraints:* What brings an experiment to an end? Galison distinguishes three levels of constraint on experiments: long-, middle-, and short-term. Some long-term constraints are theoretical, including metaphysical views of what the world could possibly be like. Galison urges that there are also long-term constraints arising from instrumental traditions, each demanding that only a certain kind of result is pertinent. Thus, the physicists who start with counters and scintillators develop the spark chamber and the wire chamber, new apparatus that will provide data different in kind from cloud chambers, bubble chambers, and nuclear emulsions. Thus, we step "down from the aristocratic view of physics that treats the discipline as if all interesting questions are structured by high theory."

His middle- and short-term constraints include some familiar ones, but also new insights. At the middle level, he emphasizes how theoretical assumptions can be *built into the apparatus itself.* Machines are not neutral probers of nature—and Galison has detailed examples to prove this. At the short-term level, he singles out, for example, the principles for routinely selecting which data to analyze, and reminds us that, at CERN, groups of physicists stand around the table "stamping IN and OUT on event candidates." This is neither rigid routine nor anarchy, but rather a craft skill, taught by apprenticeship within an experimental culture.

6. *Realism:* Galison might be read as fuelling the flames of "social construction" theories of knowledge. I think not. Usual accounts of scientific method, be they rationalist or empiricist, held that theories are true or false and that we judge of their truth value by their ability to predict and explain phenomena. Skeptical theories of a conservative and old-fashioned bent—instrumentalism, constructive empiricism—slightly changed the terms in this equation, talking of theories being adequate rather than true, that is, adequate to the phenomena,

whose objectivity and identity was never put in question. The new skepticism—social constructionalism—challenges the presupposition that phenomena investigated experimentally exist independently of social interchange. Hence, it holds that theories never have any "retroactive" truth; we do not discover the truth so much as invent and maintain it. Galison, as I read him, also treats data and even phenomena as material productions of certain experimental and instrumental traditions. It is not just that we would obtain different data in different traditions, but that what counts as data is determined by the traditions of which he has given examples. This is not, however, a form of skepticism, because Galison is keenly aware of the realities about getting anything at all out of apparatus. The real meshing of experiment with the world occurs not by finding out which theories are true to the phenomena, but by finding out the ways in which the instrumental traditions in which they are made incarnate are able systematically to interact with their materiel, subject to the three levels of constraint. We might call this technological realism, not meaning another high-falutin "scientific realism" but "realism" in the ordinary sense of the word, the realism of the person who knows that hardly anything can be made that works, and that our visions of the world's microstructure are built around that humbling fact.

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Subject, Thought, and Context. Philip Pettit and John McDowell, eds. New York: Oxford University Press, 1986. 300 p. Cloth $49.95, paper $17.95.*

This book contains an introduction by the editors and nine new essays on issues in philosophy of language and philosophy of mind. The topics include the nature of psychological explanation, folk psychology, functionalism, the individuation of linguistic and intentional content, and Wittgenstein's views about private language. On the whole, the contributions are lucid, ambitious, and carefully argued. The book is recommended with enthusiasm.

* I have been helped considerably while writing this by several conversations with Anthony L. Brueckner.

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