prove the problem-solving performance of college students by teaching them heuristics and the like.

In one study, both experimental and control groups were shown how to solve the same problems. The experimental group was given explicit instruction in the heuristics used in the solutions. Subjects in this group transferred at least some of these heuristics to new problems. (To prevent wild-goose chases in the transfer test, subjects in both groups were reminded to reassess their progress.)

In the second study, the experimental group was given an intensive course in problem solving while the control group had a course in structured programming. Again, the experimental group improved in the use of the heuristics taught and in subjective measures of control such as whether they planned their solution or just plunged into it. Analysis of protocols showed objective evidence of improved control: experimental subjects were indeed less likely to "plunge in" without evaluation. Subjects in this group also came to classify problems more in the way experts did, by methods of solution rather than superficial features. Although this result will appeal to cognitive psychologists because it employs one of their official paradigms, it adds less to our understanding than other findings.

Also presented is a framework for the analysis of problem-solving protocols that explicitly incorporates judgments of the appropriateness of control. Such a prescriptive approach to analysis ensures the relevance of the research to instructional questions. The analytic framework could, for example, serve as the basis for a tutorial approach to the teaching of problem-solving.

Schoenfeld is rightly critical of classroom practices (which he documents) that encourage rote memorization of geometric constructions, an empirical attitude toward discovery, two-minute exercises to the exclusion of real problems, "step by step" procedures, and preparation for standardized examinations. His analysis should enrich discussions of curriculum reform.

This book is worthwhile and engaging reading for anyone who teaches mathematics or related subjects at the high school or college level. It should also be read by those concerned with curriculum and policy and by scholars. It is a fine demonstration that worthwhile scholarship is possible in a prescriptive domain. It should inspire similar work in other disciplines and on other aspects of mathematics learning, for example, on understanding as distinct from problem solving, as well as efforts to discover the common features of good thinking across domains.

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# New Looks at Faraday

**Faraday Rediscovered**. Essays on the Life and Work of Michael Faraday, 1791–1867. DAVID GOODING and FRANK A. J. L. JAMES, Eds. Stockton, New York, 1985. xiv, 258 pp., illus. $70.

Michael Faraday came from a family of modest circumstances and Sandemanian faith. As a bookbinder's apprentice interested in science, he read science books that came his way and attended Humphry Davy's popular lectures at London's Royal Institution, which was founded at the turn of the century as a private institution for promoting practical scientific research and popular scientific lectures. Entering the Royal Institution as Davy's servant, Faraday eventually became the most prominent member of its staff and one of England's most famous scientists. In 1831 he discovered electromagnetic induction and in 1845 the "Faraday effect." Grounded in his experimental researches, his ideas prompted the development of field theory, greatly influencing the mathematical physics of William Thomson and James Clerk Maxwell.

Research on Faraday can draw on an enormous manuscript record of correspondence and laboratory notebooks as well as his experimental apparatus itself. Evidently, Faraday scholarship could expand into an "industry" to rival those devoted to Newton and Darwin. Though not quite an industry in itself, this excellent volume, which brings together essays by some dozen scholars, could claim to have "rediscovered" Faraday in three basic ways: as experimentalist, as member of the Royal Institution, and as Sandemanian.

Faraday has always been recognized as a consummate experimental scientist, but recent research has extensively explored his considerable theoretical insights. Though not avoiding theoretical issues, this book above all seeks to comprehend the expertise and importance of Faraday the experimenter. The chapter by David Gooding, the leading Faraday scholar these days, goes beyond description of experiments in their final form to study Faraday's development of experiments from rough beginning to polished completion. "Experiments, like experimentalists, have biographies," Gooding explains. In identifying the typical stages in the life of a Faraday experiment, Gooding can rely on Faraday's *Diary*, which "allows us to see how a scientist worked day by day, sometimes hour by hour." Ryan Tweney's chapter on induction emphasizes Faraday's strategies of experimentation, noting his searches for both confirmatory and disconfirmatory results. Tweney sees the latter as especially significant in Faraday's methodology. Frank James's chapter on Faraday's "optical mode of investigation" highlights Faraday's use of light as an experimental tool, for example in his research on magnetism and on the structure of matter. L. Pearce Williams, whose massive 1965 biography of Faraday was a milestone in the study of 19th-century science, contrasts Faraday's experimental caution with the mathematical boldness of his French contemporary André-Marie Ampère. Concentrating on experimentation, Faraday forced Ampère to retreat from his bold theorizing of the early 1820's to less hypothetical research later applauded by Maxwell.

Two chapters attempt to revise Morris Berman's 1978 discussion of Faraday and the Royal Institution, which questioned the value of each to the other. Sophie Forgan's essay on "the institutional context" of Faraday's career maintains that Faraday's research *was* appreciated by the managers of the Institution and, indeed, that the Institution was probably the best place Faraday could have been for pursuing his own research interests. Moreover, denying that the Institution declined after 1844 under Faraday's leadership, Forgan declares that it entered the last third of the 19th century stronger than ever. Gooding's chapter, too, concerns the institutional context of Faraday's experimental work, as his experiments were begun and worked out privately in the Institution's basement and then brought upstairs as polished experiments for presentation (and general acceptance) in Faraday's public lectures. Since Faraday also lived at the Institution, there was an extraordinary dovetailing of an outstanding establishment and an eminent career.

The extremely conservative Christianity of Faraday's Sandemanianism has long been known but has been little investigated with respect to his science. In an imaginative use of Sandemanian sources, Geoffrey Cantor has taken on the task in his contribution on "reading the book of nature." For Faraday, Cantor suggests, reading nature was like reading the Bible—one looked for plain, simple, literal truth. Hence, one properly relied on direct experiments, not high-powered mathematics or speculative theories.

Besides Williams's, two other chapters focus on connections between Faraday and others. David Knight's on "fathers and sons" regards Humphry Davy as the "father" both to his younger brother, John, and to Faraday. John was the good "son"; Faraday was not. Brian Bowers writes on the cooperation between Faraday and the electrician Charles Wheatstone on matters of science and technology.

Two enterprising chapters seem only partially successful. Nancy Nersessian brings an extended philosophical analysis of the definition of a concept to bear on the history of Faraday's concept of a field. Tweney's chapter, previously mentioned, employs the jargon and ideas of cognitive psychology. Both chapters reach quite reasonable historical conclusions, independent of, one feels, the philosophy and the psychology.

Elspeth Crawford, a newcomer to the field who finished her dissertation on Faraday in 1985, presents a fascinating and candid account of her struggle to understand him. She suggests that her creative moments, like Faraday's, came during a particular sort of emotional state that fostered "a mode of thinking ***different in kind*** from modes accessible to conscious processes." Faraday depended emotionally on God to assure that the technique would succeed; Crawford depended on Faraday's statement that certain passages that seemed intractable confusion to her actually constituted important clarifications in his thinking.

The book's editors are to be commended for assembling these several essays on current issues in Faraday scholarship. Providing a unifying framework for the whole, their introduction is a valuable guide to the separate discussions.

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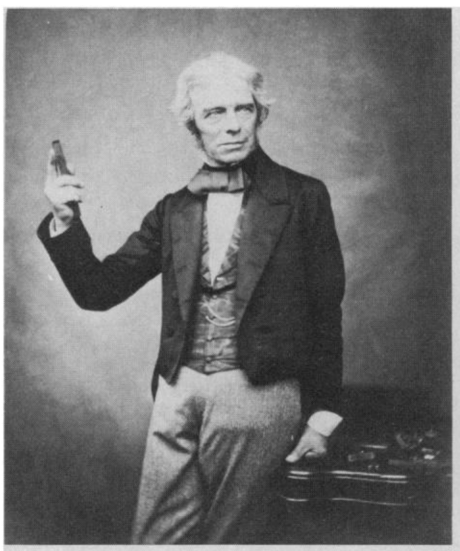

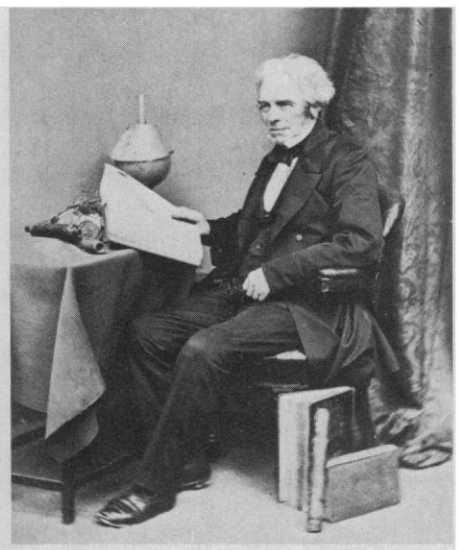

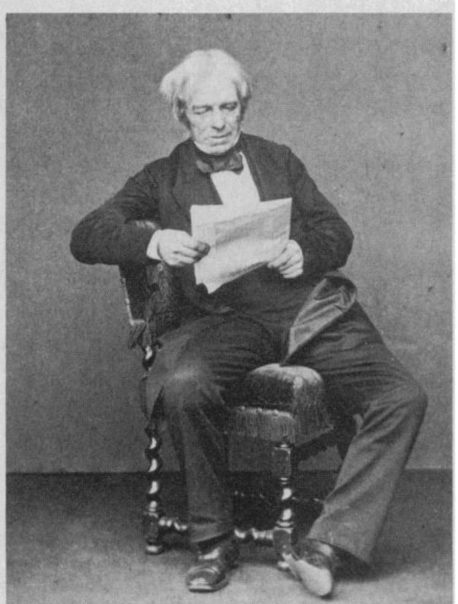

Three portraits of Faraday. "Victorians . . . were passionate collectors of memorabilia. . . . The appearance of a newly published engraved or photographic portrait of a celebrity was a newsworthy item." Faraday himself assembled two albums of portraits, now of interest both as indicative of his interests and friendships and as evidence of developments in photographic technique. In addition to being a collector of portraits, Faraday "was also keenly interested in the processes which produced them [and] promoted the development of lithography and photography through Royal Institution lectures and personal contacts with innovators." He was moreover "a willing participant in the image-making process and sat for many photographic portraitists. Some of the images are noteworthy in their reference to Faraday's particular scientific interests or his desire to be portrayed in a pose departing from standard studio types." *Top left*, "Faraday as a lecturer, demonstratively holding a bar magnet," about 1857. *Top right*, Faraday "depicted in the role of a scientific investigator . . . , seated beside a table laden with equipment relating to his experiments," 1863. *Bottom*, "the 'off-duty' Faraday shown . . . reading a newspaper with the sole of his shoe inelegantly exposed," about 1863. [From G. M. Prescott's paper in *Faraday Rediscovered*; photographs courtesy of (respectively) the National Portrait Gallery, London; the Royal Institution; and the University of Glasgow Library]

## A Debate over Experiment

**Leviathan and the Air-Pump.** Hobbes, Boyle, and the Experimental Life. STEVEN SHAPIN and SIMON SCHAFFER. Including a translation of Hobbes's *Dialogus physicus de natura aeris* by Simon Schaffer. Princeton University Press, Princeton, NJ, 1985. xiv, 442 pp., illus. $60.

Scientific instruments of the 17th century can be divided into two categories, those that were used to measure things and those that were used to refine or magnify the senses. Instruments of the first category, such as the balance and surveying instruments, had been used since antiquity, but instruments of the second, such as the telescope, the microscope, the barometer, and the air pump, appeared for the first time in the 17th century and were fundamental for the progress and success of the Scientific Revolution. Because the instruments of this second category were new, their value and their proper use were not obvious to natural philosophers, and they caused considerable controversy.

The air pump is a good subject for historical investigation because the controversy it caused involved some of the most prominent natural philosophers in Europe including Robert Boyle, Thomas Hobbes, and Christiaan Huygens. In 1658–1659 Boyle had a "pneumatical engine" constructed by the instrument maker Greatorex with the help of Robert Hooke. In 1660 he described the experiments that he had performed with this new engine in his great classic, the *New Experiments Physico-Mechanical, Touching the Spring of the Air*. The following year Thomas Hobbes attacked Boyle's experiments in his *Dialogus physicus de natura aeris*, arguing that experiments such as those Boyle performed with the air pump had no place in natural philosophy. The experimenters and the anti-experimenters joined in battle, producing the usual polemics such quarrels arouse. Henry More's condemnation of "slibber