cessful book. Despite the presence of a few problems—an arid first chapter that is rather disconnected from the rest of the volume is the biggest one—there is a lot offered here for both the specialist and the general reader. The book elevates the methodology of the case study to a level that has been previously seen only in such organizational classics such as *Union Democracy*. Most important, it reminds us of a basic truth of organizational and social life: the natural and rigid distinctions that frame our most important decisions are not necessarily either.

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A Cooperative Innovation

The American Synthetic Rubber Research Program. PETER J. T. MORRIS. University of Pennsylvania Press, Philadelphia, 1989. xii, 191 pp., illus. $34.95. The Chemical Sciences in Society.

Evaluating the effectiveness of research programs has been a problem that has plagued every industrial research director since Willis Whitney joined General Electric's new and pioneering laboratory in 1900. Because technological innovation is a process that encompasses a much larger sphere than the immediate laboratory environment, the relationship between a research program and any innovation is a complex one. At opposite ends of a spectrum, researchers can provide a host environment into which outside developments can be implanted, or they can invent and innovate radically new technologies. In this small book Peter Morris attempts to say some big things about research and innovation. Through the example of the research arm of the American synthetic rubber program, Morris asserts that cooperative research is less productive than proprietary research between competing firms, the reason being that companies undertake research to develop patented products or processes that will give them a competitive advantage. In making this assertion, Morris assumes that major developments score the most points in the research contest; but before accepting the final tally on his scorecard, it is necessary to put the research program in a broader perspective.

In late 1941 as the Japanese Empire spread into Malaya and the Dutch East Indies, the United States found itself cut off from its supply of natural rubber. To remedy this situation, the wartime government managed a massive effort to create a synthetic rubber industry based on a butadiene-styrene copolymer developed in Germany in the 1930s. American rubber companies had done some work in this area, but low prices of natural rubber had kept the work in the laboratory stage. Not only were there economic problems but technological ones as well; the rubber companies knew how to make tires, but their knowledge of petrochemicals and polymerization was limited. The wartime program overcame these obstacles—production went from virtually nothing in 1943 to 850,000 tons in 1945—because the technical capabilities of the chemical, oil, and rubber companies were combined in a cooperative effort that probably could not have happened in peacetime. Overall, synthetic rubber was a successful innovation.

In this book, Morris focuses more narrowly on the official "research" arm of the project. Founded in October 1942, this effort was initially headed by Robert R. Williams, an experienced Bell Telephone Laboratories chemist and an expert on natural rubber. Over the next year Williams enlisted 12 universities to join the program, the key figures being Carl Marvel at Illinois, Piet Kolthoff at Minnesota, and William Harkins and Morris Kharasch at the University of Chicago. Other participants were the major rubber companies, Bell Laboratories, and the National Bureau of Standards. During the war when the large-scale production of a standardized product was the goal, the researchers' role was troubleshooting and doing fundamental studies of the process and polymer. Even Morris agrees that this research was largely successful, even though it failed to develop an all-synthetic-rubber truck tire. That problem would not be solved until the mid-1950s when it became possible to make synthetic natural rubber.

After the war the government did not turn over the synthetic rubber plants to the private sector immediately because there was considerable uncertainty about the ability of synthetic rubber to compete against its natural counterpart. For strategic reasons the military wanted America to have the capability to be self-sufficient with regard to this critical material. In addition to the military concerns, the government had invested $677 million, which it hoped could be partly recouped by auctioning the plants to private industry. For these reasons, the government-funded research program continued after the war with the general goal of improving synthetic rubber until it was comparable in price and properties to natural rubber. This goal was accomplished in the late 1940s and early 1950s, but the major innovations—cold polymerized butadiene-styrene rubber, oil-extended rubber, and synthesized natural rubber—all came from outside the program. Major new innovations that come from outside established industries are commonplace in the history of technology. Very often the rewards of invention do not go to those who make the breakthrough but to those who innovate making maximum use of the new technology. This appears to have been the case in the postwar rubber industry.

With synthetic rubber on a sound economic and technological footing, the government auctioned the plants to industry in 1955, raising over $260 million. At this point the government research program was disbanded after having spent $56 million over 13 years. After 1956, funding of new synthetic rubbers fell to the military. Although a number of commentators, including Morris, have lamented the alleged waste of money by the civilian program, no one has cast a critical eye at the military programs. Industrial and academic scientists who had benefitted from the government program probably were happy to see the funding shifted to the military, where outside criticism would be muted by the exigency of the Cold War.

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Words About Invention

Inventing for Fun and Profit. JACOB RABINOW. San Francisco Press, San Francisco, CA, 1990. x, 278 pp., illus. $18.75. History of Technology Monographs.

Engineers are notoriously nonverbal, preferring to think and work in the media of drawings and numbers. When they put pencil to paper, it is more than likely to sketch a new idea or to calculate a new arrangement of materials and things. But engineering drawings and calculations are not ends in themselves, for they serve mainly to communicate the artifact to other engineers, to machinists, and to technicians. When the artifact is realized in tangible form, the drawings and calculations are often forgotten until the artifact misfunctions or modifications are in order.

The most creative of engineers seldom put pen to paper after their pencil dreams have been realized, but perhaps this is more for lack of interest or purpose than for lack of talent. After all, the artifact can then speak for itself, except perhaps in the arcane literature of the patent office, where those quintessential engineers—the inventors—must constrain and convolute the issue of their pens in ways they never would that of their pencils. Inventors in thrall to patent lawyers produce a legalese that can do little to encourage writing of a more human and engaging kind.

As if to reinforce the conventional wisdom about how uninspired engineers are with words, the octogenarian inventor Jacob Rabinow has entitled his first full-length book *Inventing for Fun and Profit*. If titles could be patented or copyrighted, this one long ago would have been. But the reader who does not prejudge a book by its cover will find a rare treat here.

Rabinow immediately captures the reader's attention by posing in chapter 1 a series of ten problems that led to some of his own inventions. The problems include: how to design a watch that can be adjusted without being opened; how to premix nail polish; how to design an electrical relay that operates without bouncing; how to design an automatic headlight-dimming device; how to design automatic mail-sorting machinery for the Post Office. The list gives but an incomplete indication of the range of interests of this holder of 225 patents, and Rabinow's promise that his solutions to the problems are spread throughout the subsequent chapters is an effective literary device for drawing the reader into the book.

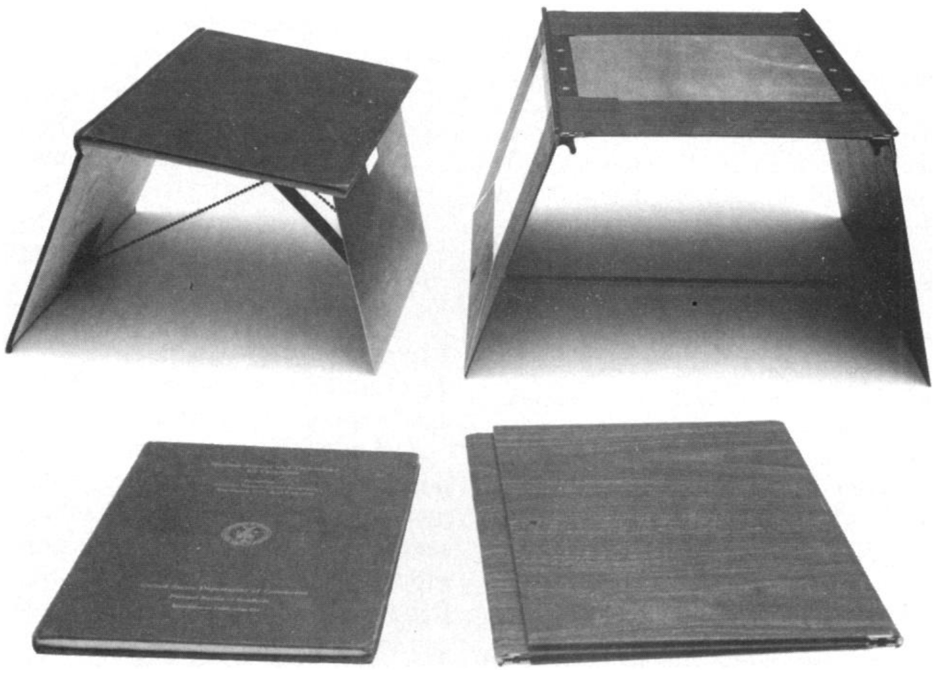
Inventing for Fun and Profit is more than a list of problems and one man's set of solutions, however. This is also a book about the course of one inventor's life and career, and the autobiographical anecdotes and details nicely balance the more technical excursions. Indeed, Rabinow's personal and professional lives seem so naturally integrated in this book that it reads at times like a paradigm for the good life. The inventor's home is an extension of his laboratory, and vice versa; the inventor's leisure is an extension of his work, and vice versa.

Rabinow was born in Russia in 1910 and came to America at the age of 11. He received degrees in electrical engineering from the City College of New York, but the Depression offered few opportunities for a new college graduate with a foreign accent and little experience. Rabinow passed several years working in radio factories and taking Civil Service exams. After some Kafkaesque experiences with his file, he tracked down his papers in a mechanical engineering section of what was then the National Bureau of Standards, where he was hired in 1938. His first duties involved calibrating instruments, but soon he was working on ordnance problems. Among the many interesting aspects of Rabinow's book are his descriptions of an atmosphere at the NBS whereby tangential but unfunded research was "bootlegged" under an enlightened management.

One of the most protracted parts of Rabinow's book describes efforts to automate what was then the Post Office, and he gives considerable insight into problems associated with optical character recognition and sorting machines. As in other technical discussions, Rabinow takes the opportunity to discuss nontechnical influences on and aspects of the problem. In particular, he considers the role of research and development in a multibillion-dollar operation such as the Post Office and concludes that the enterprise was sorely underfunded. Similarly, Rabinow considers later in his book the familiar theme of Japanese versus American commitments to research and development. While his conclusions about lawyers, accountants, and engineers are familiar ones, they are reinforced by the context of concrete experiences into which they are placed.

Rabinow describes leaving NBS in his early 40s to start his own firm, and his descriptions of the relationships between the technical and entrepreneurial temperaments are a valuable component of his book. His examples of the financial aspects of particular inventions give some valuable perspectives on profitability and its necessity for invention. After about 20 years as an independent businessman, Rabinow returned to the NBS.

In the closing pages of the book Rabinow reflects on the nature of invention and reports a measure of his "invention rate" as a function of time. By plotting the number of new ideas recorded in his notebooks spanning 50 years, he observes that his invention rate increased dramatically when he opened his own business. By becoming a consultant he had many problems thrown at him by clients, and he could follow those problems where they took him because he had "enough staff and time and money" to give a back-of-the-envelope sketch to a good mechanic and go about other things until a model was ready. When he returned to the Bureau of Standards in 1972 Rabinow "sat at a desk and ran three programs" and thus



Folding footrest devised by Jacob Rabinow to increase the comfort of a short theater-going companion. "I went to the Publications Department of the National Bureau of Standards, which publishes a great many books, copies of which have to be discarded when there are too many. . . . I asked if they had a dark covered book, about ½ in. thick, fairly large. . . . They asked in what subject I was interested. I said I didn't really care. . . . I got a book, glued the pages together, cut out the centers like all the smugglers in the world do, and made a folding footstool. The easiest way to describe it is that inside the cut-out section I hinged some aluminum plates so that when you open the cover and swing out an aluminum plate, adjust some struts, hook some chains in the right places, and turn it over, you have a footstool." [From *Inventing for Fun and Profit*] found it "very difficult to invent."

While *Inventing for Fun and Profit* can be read for pleasure by the general reader, there is much in it to reward the specialist. Inventors can of course learn a lot from this master, but students of inventors and invention will also find much more than the title suggests. Rabinow gives a first-hand account of the mind of the engineer at work, and he shows how the visual and nonverbal dominate that mind. He shows how much of a social act invention is, for the interaction between inventor and society is paramount in providing problems and restricting solutions. In short, Rabinow places technical innovation in the much broader contexts in which it must take place, and he does it all in a totally engaging manner.

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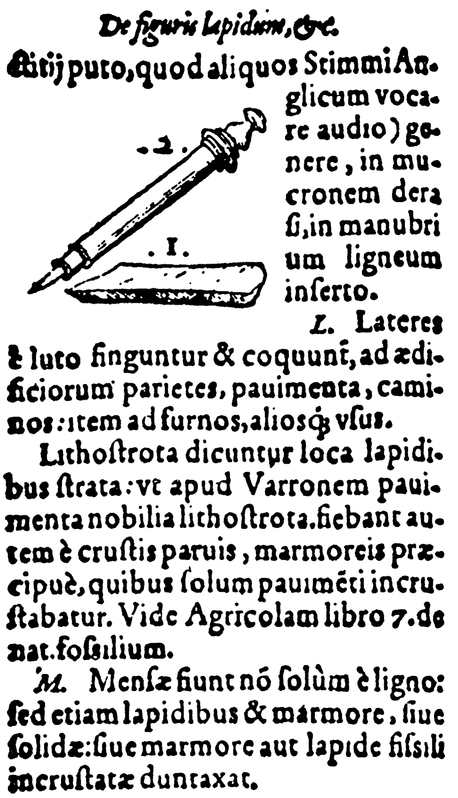
Technology of the Ubiquitous

The Pencil. A History of Design and Circumstance. HENRY PETROSKI. Knopf, New York, 1990. xx, 434 pp., illus. $25.



De figuris Lapidum, &c.
Ætij puto, quod aliquos Stimmi Anglicum vocare audio) generę, in mucronem derasi, in manubrium ligneum inserto.
L. Lateres è luto finguntur & coquunt, ad ædificiorum parietes, pauimenta, caminos: item ad furnos, aliosq; vsus.
Lithostrota dicuntur loca lapidibus strata: vt apud Varronem pauimenta nobilia lithostrota. fiebant autem è crustis paruis, marmoreis præcipuè, quibus solum pauimēti incrustabatur. Vide Agricolam libro 7. de nat. fossilium.
M. Mensæ fiunt nō solùm è ligno: sed etiam lapidibus & marmore, siue solidæ: siue marmore aut lapide fissili incrustatæ duntaxat.

"The first known illustration of a lead pencil," from Konrad Gesner's *De Rerum Fossilium.* (1565), "pictured beside a piece of the mineral from which its marking point was made." [From *The Pencil*]

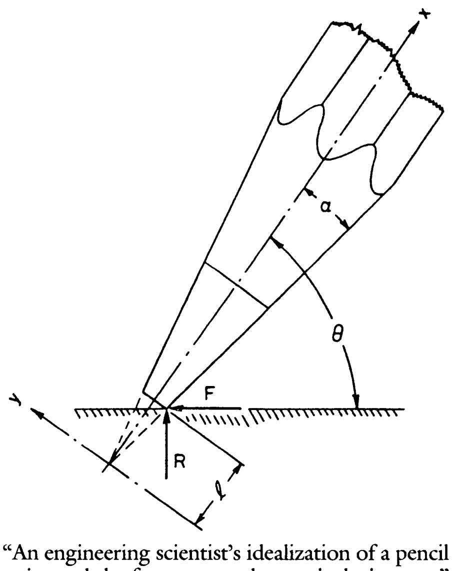
Read this book and you will never look at pencils the same way. But it is probably safe to say that this is true for anything or anyone about which one has read 350 pages. So what? If you have ever sat staring at your pencil, wondering all that one can ask about such things—why is it yellow? why is it hexagonal? why does it start out 7 inches long? what is it made of? where did it come from?—then this book will satisfy your curiosity. But for the rest of us, this is not quite the motive to send us to *The Pencil.*

Henry Petroski, civil engineering professor, is prepared for us, however. To him, "pencil making is a near-perfect metaphor for engineering" (p. 338). That such a claim should be central to this work should come as no surprise to anyone acquainted with Petroski's earlier work, such as *To Engineer Is Human* and *Beyond Engineering*. The author is, in fact, one of the most eloquent spokesmen for the central role of engineering, not only in shaping our material environment but in defining our modern culture. It is thus particularly appropriate that the one figure who pops up again and again in this story is Henry David Thoreau. Thoreau himself is a kind of metaphor for Petroski's tale, for the transcendentalist philosopher was also a pencil manufacturer, and it is in explaining the linkages between these two roles that we find the most stimulating and original contributions in this book.

Everything has a history, and Petroski has done a nice job putting together a story that goes back to the mid-16th century, when the Swiss naturalist Konrad Gesner described a writing tool made "from a sort of lead." The discovery of graphite deposits in England's Lake District is credited with leading to the creation of the first carefully made wood-cased pencils. The quality of these tools was directly linked to the graphite that was carefully sliced and shaped to fit into their cases. In the recapitulation of a tale common in the history of materials, dependence on a relatively scarce substance (the high-quality Cumberland graphite) led to the careful experiments of Nicholas-Jacques Conté in the late 18th century that gave us the modern baked graphite-clay pencil "lead." Indeed, Petroski makes clear that the technical refinement of pencils was usually dependent on the ability to manipulate and improve materials. The actual design of the device, after all, changed only slightly through the centuries, being shaped as much by popular perceptions and commercial campaigns as by technical considerations.

The cultural expectations that molded these perceptions and the economic and social considerations that influenced business enterprise are every bit as much part of Petroski's story as the technical history. The rise of the once-dominant German pencil industry, for example, may be seen as a case study in the circumstances that allowed German industry in general to play such a disproportionate role on the world stage in the late 19th century. Similarly, the precociousness of American efforts to mechanize pencil making fits neatly into more general images of what made 19th century American industry so distinctive. Indeed, the story told here of entrepreneurs, inventors, family networks (just keeping straight the list of various pencil-making Fabers, from Anton to Wilhelm, is no small task), and bureaucratic intrusions is as fine a case study as one will find of the key historical elements that have shaped modern material life.

As such, *The Pencil* is an admirable addition to an honorable and useful literature. In another context, perhaps, this extended treatment of an artifact and its historical development would be called "antiquarianism," and its audience would be an appreciative, but small, group of collectors, like-minded scholars, and students of the minutiae of material culture. Petroski's book, however, has been packaged and promoted as something else—a popular exposition of the character and dynamics of modern technology. "The story of a single object told in depth," Petroski claims, "can reveal more about the whole of technology and its practitioners than a sweeping survey of all the triumphant works of civil, mechanical, electrical, and every other kind of engineering." To make sure that his readers do not miss the point, Petroski interrupts his narrative with some frequency to say that such-and-such a problem in pencil-making is just like that encountered by bridge builders. The implication here, curiously enough, is that



"An engineering scientist's idealization of a pencil point and the forces exerted upon it during use." [Drawing by Fred Avent; from *The Pencil*]