provides concrete examples of homework problems, exam questions and illustrative phenomena that can be used to trigger insight. I have already asked students to discuss the change in pressure that occurs when two immiscible liquids separate out in a narrow necked jar. I am looking forward to using Newton's derivation of centripetal acceleration. I plan to try out the illustration of Faraday's law in a multiply connected region. The book offers physics teachers a number of ideas for immediate use in the classroom.

The book is eye opening and informative, but is its program for improving the teaching of introductory physics feasible? There are two issues here. One is practical. How much time is available for Socratic questioning of students? If it takes 20 to 30 minutes to begin to straighten out one student's misunderstandings of one concept, is this an approach that can be used in a course of 100 students—let alone 1000 students? Students need more time to chew over the ideas of beginning physics, and they need closer guidance as they chew. Where will the time and guidance come from?

The second issue is more basic. How worthwhile is the investment of these resources in generating understanding? I assume "understanding" means the ability to apply correctly the generalizations of physics to specific cases, particularly to ones that have not been met before. Is this kind of comprehension a realistic goal for introductory physics? I doubt that comprehension of a general principle is ever "taught"; I think it occurs in the mind of the learner, often dealing with many different examples of the embodying principle. When I try to remember getting my own misconceptions straightened out, I am struck by how late this occurred in my education. It certainly did not happen in the introductory physics course, which I remember as a kind of interestingly mysterious experience through which I wandered in a daze.

Throughout the book and especially in the concluding two essays, "Achieving Wider Scientific Literacy" and "Critical Thinking," Arons offers the elements of a philosophy of science teaching. Unfortunately they are only elements. His assumptions are not examined closely and the relative weights that he gives them shift. Important issues are not raised. For example, Arons repeatedly argues that "less is more." Less coverage can be transformed into more understanding. He offers some evidence for this, but the issue is one of balance. How much coverage are you trading for how much understanding? His basic assumption is that understanding is good, coverage less good. This assumption needs examination.

As another example, his deprecation of vocabulary as a substitute for understanding is often to the point, but it also shows a parochialism common to physicists. Language is extremely important. Many people, especially nonscience students, make little distinction between the names of things and their reality. It is unrealistic to deplore and ignore this important human trait; it is probably better to exploit it. Arons's stimulating and provocative ideas and opinions are the elements of an educational philosophy; they need to be subjected to philosophical analysis.

The curricular seas of physics have been calm for more than 20 years, but the waters are stirring. Arons has some navigational advice for us—much of it common sense: Learning physics must not be like drinking from a fire hose. Students must come away with some feeling of achievement and satisfaction; the experience cannot be one of unrelieved frustration.

We need to listen to Arons. We do our subject a disservice and fail as teachers if we replace one fire hose with another, or if we substitute exotic taxonomies of quarks and gluons, black holes, band structure or quantum fields for the harder tasks of equipping students with the tools and concepts for independent analysis of the physical world. Arons's book warns against such failings, and it offers practical, useful and stimulating ways to avoid the pitfalls of superficiality. The tacit and explicit assumptions of his views of physics education should stimulate a debate that we need. If you teach physics at any level of the curriculum, read this book.

Discovering: Inventing and Solving Problems at the Frontiers of Scientific Knowledge

Robert S. Root-Bernstein
Harvard U. P., Cambridge, Mass., 1989. 501 pp. $35.00 hc ISBN 0-674-21175-8

In the mid-1960s I served for a time as book review editor for a quarterly educational journal. In the welter of books that poured in, there was one category that seemed to predominate. I still describe it as publishing's infinite sink: Creativity—what it is, who has exhibited it in the past and why, how to nurture it, how not to discourage it, how to develop curricula to promote it, which teaching styles foster it and which discourage it. Many of these books were edited collections of conference papers. Others were collections of reprints of essays and excerpts from monographs, while still others were book-length exegeses exhorting us to be more creative and warning us of the dire consequences to our national vitality if we did not reinforce behaviors among our young that lead to creative adults.

Creativity comes in all shades and all shapes. In truth, we don't know much about what it takes to be a creative person, and we have even less of an idea of how to foster whatever characteristics might be pertinent. Yet the torrent of treatises continues unabated. Still, every once in a while a book on the subject of creativity comes along that forces its way to attention. Such a book is Robert Scott Root-Bernstein's *Discovering.*

Root-Bernstein is a productive biochemist who has made his reputation in science by, among other things, successfully challenging the central dogma in molecular biology by demonstrating that amino-acid pairing allows for direct protein replication. Root-Bernstein has also published many studies on the creative process. And he is well grounded in the history of science: His doctoral dissertation was devoted to the history of the creation of physical chemistry.

Root-Bernstein's proclaimed purpose in this work is to demonstrate how the objective edifice of science is created by human beings who, like all of us, are subject to the ebb and flow of emotions, prejudices and biases. As in some of his other studies, in *Discovery* Root-Bernstein uses the history of science as a heuristic device for exploring "how ... subjective and fallible human minds can nonetheless produce something as powerful as science." But there is a subtext. Root-Bernstein is trying, desperately, to understand the creative process—the creative act. In this work, which he describes as "a colloquium on discovery," he mines history for clues on how to be creative.

While I think such efforts must of needs fail, Root-Bernstein has produced a fascinating Socratic dialogue in which he uses the history of science to reconstruct the conditions surrounding a few key discoveries in chemistry and biochemistry. In the tradition of the dialogues of Galileo, Root-Bernstein has created a modern cast of characters who embark on a six-day exploration.

In the course of these six days, a number of case studies are explored. These include Claude Louis Berthollet's struggle to understand what is today called "mass action"; Louis Pasteur's work on the connection between optical activity and living processes; Alexander Fleming's work on penicillin; and Root-Bernstein's own discovery of protein–protein transcription. Along the way, one encounters snippets ranging from the work of Galileo to the work of Einstein, of Bohr and of Feynman. There are long, discursive investigations of the history and of the philosophy of science, all of it aimed at uncovering the essential features of the conditions under which discovery takes place: Are there really such things as accidental discoveries? Are theories confirmed? Are they falsified? Are data anything more than propaganda for an already established point of view? Does an aesthetic temperament make a difference? What role does the social milieu play in the right question being asked at the right time? This culminates in a summation—a so-called "Manual of Strategies for Discovering"—containing 93 mutually contradictory principles. In the end one is quite worn out. Perhaps that is the point. But the result is an ultimately unsatisfying sense of frustration. For me the frustration is not that there are no clear answers, but that the field of questions has been muddied. For as one of the characters in the dialogue very properly points out, in scientific inquiry it is not the answers but the questions that last.

Galileo used his dialogues as a bully pulpit to focus our attention on a single issue—for example, the choice between two cosmologies, between two views of the strength of materials or between two theories of motion. Ultimately, the intricate, idiosyncratic structure of Bernstein's dialogue distracts our gaze and intrudes on our concentration. (An index that included more than proper names would have heightened my appreciation for the idiosyncratic nature of the format.)

At the finish one is left at the point where we entered: The more we examine our navels in search of the crucial variables in the creative act, the more fugitive it becomes. As a historian of science interested in using the history of science as a heuristic tool for educating nonscientists, I know all too well that any case study can be used in the service of virtually any epistemological or ontological viewpoint. The secret is not in discovering how to discover. The secret may be contained in Percy Bridgman's dictum concerning the scientific method: It is, Bridgman insisted, nothing more than "doing one's damnedest with one's mind, no holds barred." If we take that dictum seriously, I am confident that creativity will take care of itself. I suspect Root-Bernstein thinks so too.

STANLEY GOLDBERG
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Currents of Death: Power Lines, Computer Terminals and the Attempt to Cover Up Their Threat to Your Health

Paul Brodeur
Simon and Schuster, New York, 1989. 333 pp. $19.95 hc ISBN 0-671-67845-0

Cross Currents: The Promise of Electromedicine, The Perils of Electropollution

Robert O. Becker
Jeremy P. Tarcher, Los Angeles, 1990. 336 pp. $19.95 hc ISBN 0-87477-536-1

The possibility of health effects from exposure to nonionizing radiation and extremely-low-frequency electric and magnetic fields—including the power-line frequencies of 60 and 50 hertz—is becoming a serious scientific, political and perhaps economic question. In recent years experimental and epidemiological studies have suggested that unexplained field–cell interaction mechanisms may affect the nervous, circadian and immune systems, and perhaps lead to or exacerbate such health problems as cancer and chronic depression. But the science has not progressed to the point of providing a coherent theory of the observed phenomena. Individuals as well as organizations are faced with making decisions on what, if anything, they should do to minimize the potential health effects. The scientific uncertainty and the economic stakes have caused those with vested interests to take the position that we currently do not know enough to warrant concerted action. Some have chosen to deny the evidence. This certainly compounds the public's confusion and bewilderment.

The conventional argument has been that the 60-Hz and similar low-frequency fields we encounter daily are harmless because the energy quanta are too small to cause ionization, and their intensities are too weak to produce any significant heating of the tissue. However, some cellular-level experiments have shown that these fields may cause changes in the action of the cell membrane. This can lead to alterations of the rates of critical processes such as calcium efflux from brain tissue, which may in turn influence processes of growth and development, of critical periodicities in the nervous system and other biochemical feedback mechanisms, and of immune resistance. Epidemiological studies have shown an association between residential-level fields and childhood and adult leukemia, and between occupational-level fields and leukemia and brain tumors. Studies on rats have shown that the fields affect the rhythm of pineal melatonin, a chemical that in humans has been associated with chronic depression and tumor growth rates. To complicate matters, cellular phenomena show frequency and intensity resonances, as well as nonlinear variations with the period of exposure. The biology and physics of the fields' interaction with the cell membrane have not developed to the point where we can say what measure of field exposure represents "dose." It is not clear if the effects of sinusoidal fields of low frequency, such as those produced by electric power systems are similar to pulsed fields, which are created by devices such as the video display terminal, or to megahertz radio-frequency fields.

A gifted veteran writer of *The New Yorker* magazine, Paul Brodeur could have used his book to render the public a service by writing a clear exposition of the difficult scientific concepts, the status of scientific knowledge at this time, the ongoing scientific process, the conflicts between the believers and the nonbelievers, and the varying reasons why some parties do not accept the evidence of health effects. To some extent, he does address these issues, and in so doing tells a dramatic story. He speaks about how the understanding of the effects has unfolded, how some skeptical agencies have delayed the checking of preliminary data and how other parties have used political means to refute the evidence rather than attempt to replicate it.

Currents of Death indeed tells these stories in a captivating style. Brodeur has carefully researched most of the details and anecdotes. The original