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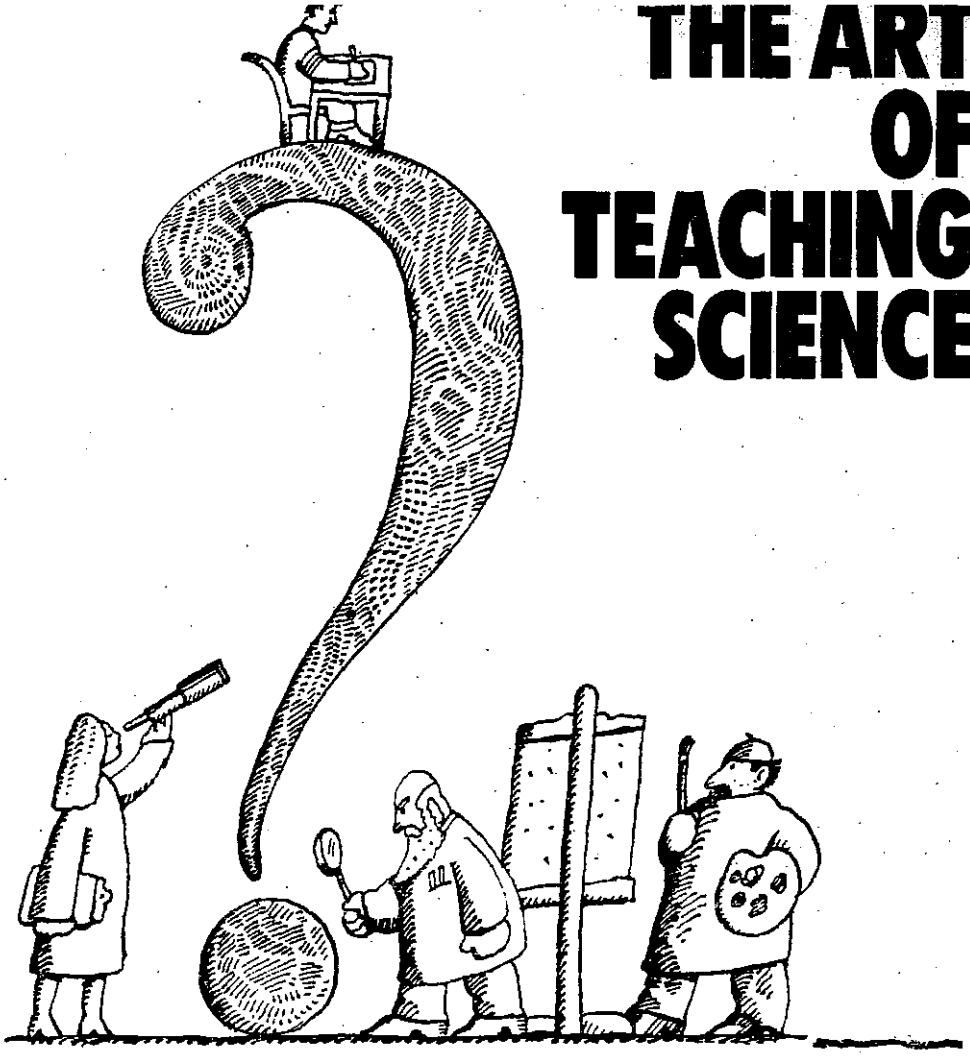
THE ART OF TEACHING SCIENCE



MARC ROSENTHAL

By Lewis Thomas

Everyone seems to agree that there is something wrong with the way science is being taught these days. But no one is at all clear about when it went wrong or what is to be done about it. The term "scientific illiteracy" has become almost a cliché in educational circles. Graduate schools blame the colleges; colleges blame the secondary schools; the high schools blame the elementary schools, which, in turn, blame the family.

I suggest that the scientific community itself is partly, perhaps largely, to blame. Moreover, if there are disagreements between the world of the humanities and the scientific enterprise as to the place and importance of science in a liberal-arts education and the role of science in 20th-century culture, I believe that the scientists are themselves responsible for a general misunderstanding of what they are really up to.

During the last half-century, we have been teaching the sciences as though they were the same collection of academic subjects as always, and — here is what has really gone wrong — as though they would always be the same. Students learn today's biology, for example, the same way we learned Latin when I was in high school long ago: first, the fundamentals; then, the underlying laws; next, the essential grammar and, finally, the reading of texts. Once mastered, that was that: Latin was Latin and forever after would always be Latin. History, once learned, was history. And biology was precisely biology, a vast array of hard facts to be learned as fundamentals, followed by a reading of the texts.

Furthermore, we have been teaching science as if its facts were somehow superior to the facts in all other scholarly disciplines — more fundamental, more solid, less subject to subjectivism, immutable. English literature is not just one way of thinking; it is all sorts of ways; poetry is a moving target; the facts that underlie art, architecture and music are not really hard facts, and you can change them any way you like by arguing about them. But science, it appears, is an altogether different kind of learning: an unambiguous, unalterable and endlessly useful display of data that only needs to be packaged and installed somewhere in one's temporal lobe in order to achieve a full understanding of the natural world.

And, of course, it is not like this at all. In real life, every field of science is incomplete, and most of them — whatever the record of accomplishment during the last 200 years — are still in their very earliest stages. In the fields I know best, among the life sciences, it is required that the most expert and sophisticated minds be capable of changing course — often with a great lurch — every few years. In some branches of biology the mind-changing is occurring with accelerating velocity. Next week's issue of any scientific journal can turn a whole field upside down, shaking out any number of immutable ideas and installing new bodies of dogma.

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chemistry, in materials research, in neurobiology, in genetics, in immunology.

On any Tuesday morning, if asked, a good working scientist will tell you with some self-satisfaction that the affairs of his field are nicely in order, that things are finally looking clear and making sense, and all is well. But come back again on another Tuesday, and the roof may have just fallen in on his life's work. All the old ideas — last week's ideas in some cases — are no longer good ideas. The hard facts have softened, melted away and vanished under the pressure of new hard facts. Something strange has happened. And it is this very strangeness of nature that makes science engrossing, that keeps bright people at it, and that ought to be at the center of science teaching.

The conclusions reached in science are always, when looked at closely, far more provisional and tentative than are most of the assumptions arrived at by our colleagues in the humanities. But we do not talk much in public about this, nor do we teach this side of science. We tend to say instead: These are the facts of the matter, and this is what the facts signify. Go and learn them, for they will be the same forever.

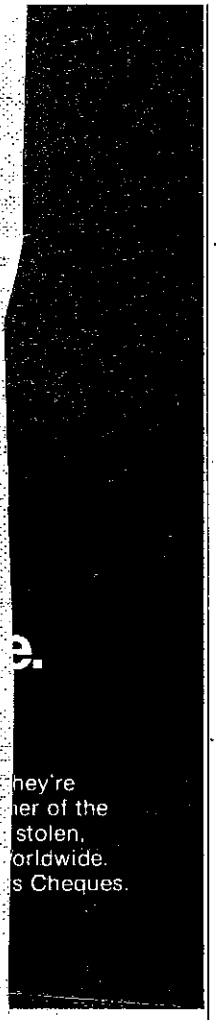
By doing this, we miss opportunity after opportunity to recruit young people into science, and we turn off a good many others who would never dream of scientific careers but who emerge from their education with the impression that science is fundamentally boring.

Sooner or later, we will have to change this way of presenting science. We might begin by looking more closely at the common ground that science shares with all disciplines, particularly with the humanities and with social and behavioral science. For there is indeed such a common ground. It is called bewilderment. There are more than seven times seven types of ambiguity in science, all awaiting analysis. The poetry of Wallace Stevens is crystal clear alongside the genetic code.

One of the complaints about science is that it tends to flatten everything. In its deeply reductionist way, it is said, science removes one mystery after another, leaving nothing in the place of mystery but data. I have even heard this claim as explanation for the drift of things in modern art and modern music: Nothing is left to contemplate except randomness and senselessness; God is nothing but a pair of dice, loaded at that. Science is linked somehow to the despair of the 20th-century mind. There is almost nothing unknown and surely nothing unknowable. Blame science.

I prefer to turn things around in order to make precisely the opposite case. Science, especially 20th-century science, has provided us with a glimpse of something we never really knew before, the revelation of human ignorance. We have been accustomed to the belief, from one century to another, that except for one or two mysteries we more or less comprehend everything on earth. Every age, not just the 18th century, regarded itself as the Age of Reason, and we have never lacked for explanations of the world and its ways. Now, we are being brought up short. We do not understand much of anything, from the episode we rather dismissively (and, I think, defensively) choose to call the "big bang," all the way down to the particles in the atoms of a bacterial cell. We have a wilderness of mystery to make our way through in the centuries ahead. We will need science for this but not science alone. In its own time, science will produce the data and some of the meaning in the data, but never the full meaning. For perceiving real significance when significance is at hand, we will need all sorts of brains outside the fields of science.

It is primarily because of this need that I would press for changes in the way science is taught. Although there is a perennial need to teach the young people who will be doing the science themselves, this will always be a small minority. Even more important, we must



will be needed for thinking about it, and that means pretty nearly everyone else — most of all, the poets, but also artists, musicians, philosophers, historians and writers. A few of these people, at least, will be able to imagine new levels of meaning which may be lost on the rest of us.

In addition, it is time to develop a new group of professional thinkers, perhaps a somewhat larger group than the working scientists and the working poets, who can create a discipline of scientific criticism. We have had good luck so far in the emergence of a few people ranking as philosophers of science and historians and journalists of science, and I hope more of these will be coming along. But we have not yet seen specialists in the fields of scientific criticism who are of the caliber of the English literary and social critics F. R. Leavis and John Ruskin or the American literary critic Edmund Wilson. Science needs critics of this sort, but the public at large needs them more urgently.

I suggest that the introductory courses in science, at all levels from grade school through college, be radically revised. Leave the fundamentals, the so-called basics, aside for a while, and concentrate the attention of all students on the things that are not known. You cannot possibly teach quantum mechanics without mathematics, to be sure, but you can describe the strangeness of the world opened up by quantum theory. Let it be known, early on, that there are deep mysteries and profound paradoxes revealed in distant outline by modern physics. Explain that these can be approached more closely and puzzled over, once the language of mathematics has been sufficiently mastered.

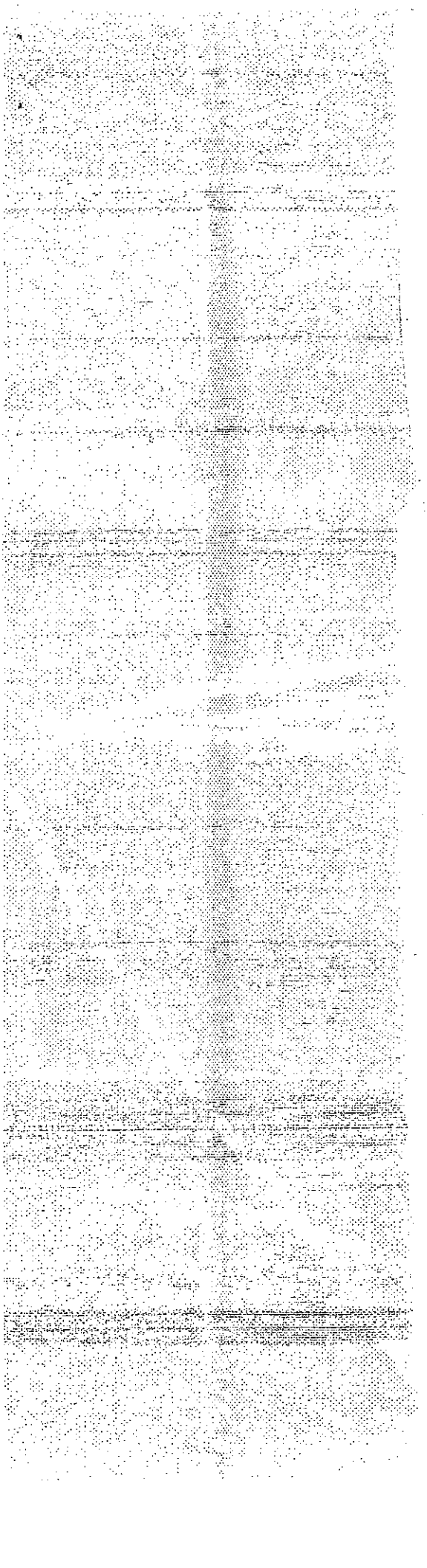
At the outset, before any of the fundamentals, teach the still imponderable puzzles of cosmology. Describe as clearly as possible, for the youngest minds, that there are some things going on in the universe that lie still beyond comprehension, and make it plain how little is known.

Do not teach that biology is a useful and perhaps profitable science; that can come later. Teach instead that there are structures squirming inside each of our cells that provide all the energy for living. Essentially foreign creatures, these lineal descendants of bacteria were brought in for symbiotic living a billion or so years ago. Teach that we do not have the ghost of an idea how they got there, where they came from, present structure and function. The details of oxidative phosphorylation and photosynthesis can come later.

Teach ecology early on. Let it be understood that the earth's life is a system of interdependent creatures, and that we do not understand at all how it works. The earth's environment, from the range of atmospheric gases to the chemical constituents of the sea, has been held in an almost unbelievably improbable state of regulated balance since life began, and the regulation of stability and balance is somehow accomplished by the life itself, like the autonomic nervous system of an immense organism. We do not know how such a system works, much less what it means, but there are some nice reductionist details at hand, such as the bizarre proportions of atmospheric constituents, ideal for our sort of planetary life, and the surprising stability of the ocean's salinity, and the fact that the average temperature of the earth has remained quite steady in the face of at least a 25 percent increase in heat coming in from the sun since the earth began. That kind of thing: something to think about.

Go easy, I suggest, on the promises sometimes freely offered by science. Technology relies and depends on science these days, more than ever before, but technology is far from the first justification for doing research, nor is it necessarily an essential product to be expected from science. Public decisions about the future of technology are totally different from decisions about science, and the two enterprises should not be tangled together. The central task of science is to arrive, stage by stage, at a clearer comprehension of nature, but this does not at all mean, as it is sometimes claimed to mean, a search for mastery over nature.

Science may someday provide us with a better understanding of ourselves, but never, I hope, with a set of technologies for doing something or other to improve ourselves. I am made nervous by assertions that human consciousness will someday be unraveled by research, laid out for close scrutiny like the workings of a computer, and then — and *then* . . . ! I hope with some fervor that we can learn a lot more than we now know about the human mind, and I see no reason why this strange puzzle should remain forever and entirely beyond us. But I would be deeply disturbed by any prospect that we might use the new knowledge in order to begin doing something about it — to im-



prove it, say. This is a different matter from searching for information to use against schizophrenia or dementia, where we are badly in need of technologies, indeed likely one day to be sunk without them. But the ordinary, everyday, more or less normal human mind is too marvelous an instrument ever to be tampered with by anyone, science or no science.

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The education of humanists cannot be regarded as complete, or even adequate, without exposure in some depth to where things stand in the various branches of science, particularly, as I have said, in the areas of our ignorance. Physics professors, most of them, look with revulsion on assignments to teach their subject to poets. Biologists, caught up by the enchantment of their new power, armed with flawless instruments to tell the nucleotide sequences of the entire human genome, nearly matching the physicists in the precision of their measurements of living processes, will resist the prospect of broad survey courses; each biology professor will demand that any student in his path master every fine detail within that professor's research program.

The liberal-arts faculties, for their part, will continue to view the scientists with suspicion and apprehension. "What do the scientists want?" asked a Cambridge professor in Francis Cornford's wonderful "Microcosmographia Academica." "Everything that's going," was the quick answer. That was back in 1912, and scientists haven't much changed.

But maybe, just maybe, a new set of courses dealing systematically with ignorance in science will take hold. The scientists might discover in it a new and subversive technique for catching the attention of students driven by curiosity, delighted and surprised to learn that science is exactly as the American scientist and educator Vannevar Bush described it: an "endless frontier." The humanists, for their part, might take considerable satisfaction in watching their scientific colleagues confess openly to not knowing everything about everything. And the poets, on whose shoulders the future rests, might, late nights, thinking things over, begin to see some meanings that elude the rest of us. It is worth a try.

I believe that the worst thing that has happened to science education is that the fun has gone out of it. A great many good students look at it as slogging work to be got through on the way to medical school. Others are turned off by the premedical students themselves, embattled and bleeding for grades and class standing. Very few recognize science as the high adventure it really is, the wildest of all explorations ever taken by human beings, the chance to glimpse things never seen before, the shrewdest maneuver for discovering how the world works. Instead, baffled early on, they are misled into thinking that bafflement is simply the result of not having learned all the facts. They should be told that everyone else is baffled as well — from the professor in his endowed chair down to the platoons of postdoctoral students in the laboratories all night. Every important scientific advance that has come in looking like an answer has turned, sooner or later — usually sooner — into a question. And the game is just beginning.

If more students were aware of this, I think many of them would decide to look more closely and to try and learn more about what *is* known. That is the time when mathematics will become clearly and unavoidably recognizable as an essential, indispensable instrument for engaging in the game, and that is the time for teaching it. The calamitous loss of applied mathematics from what we might otherwise be calling higher education is a loss caused, at least in part, by insufficient incentives for learning the subject. Left by itself, standing there among curriculum offerings, it is not at all clear to the student what it is to be applied to. And there is all of science, next door, looking like an almost-finished field reserved only for chaps who want to invent or apply new technologies. We have had it wrong, and presented it wrong to class after class for several generations.

An appreciation of what is happening in science today, and how great a distance lies ahead for exploring, ought to be one of the rewards of a liberal-arts education. It ought to be good in itself, not something to be acquired on the way to a professional career but part of the cast of thought needed for getting into the kind of century that is now just down the road. Part of the intellectual equipment of an educated person, however his or her time is to be spent, ought to be a feel for the queernesses of nature, the inexplicable thing, the side of life for which informed bewilderment will be the best way of getting through the day. ■