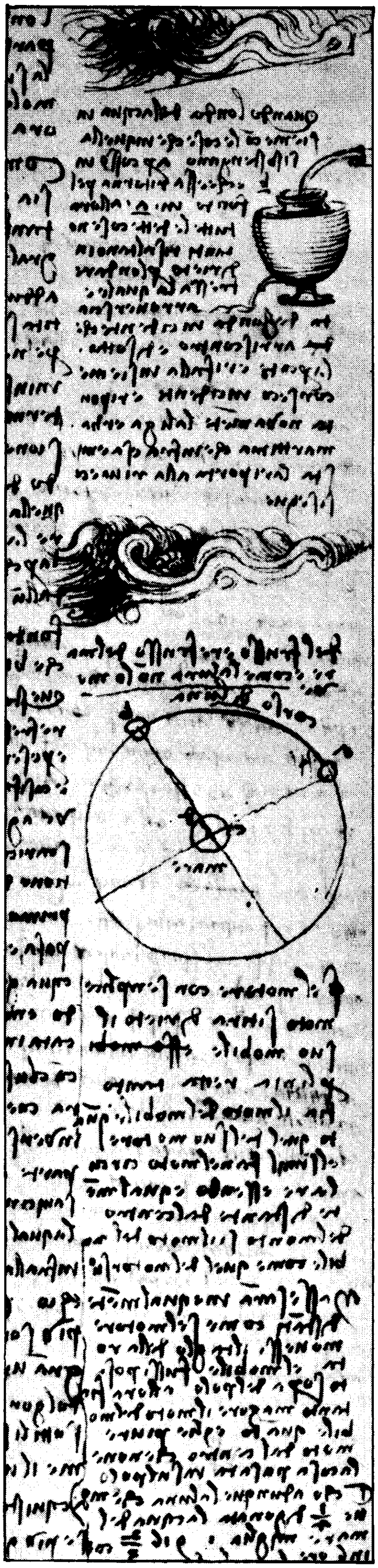


Da Vinci's marginal notes on water and tidal forces. He concluded that the moon is not responsible for tides on Earth. (From The Codex Leicester, courtesy of The Armand Hammer Foundation.)

From Theory to Praxis

Columbia can and should include science in the general education curriculum. Here's how we might begin.

by Robert Pollack '61
Professor of Biological Sciences

Is the College properly teaching science?

At first this question may seem fatuous, since the University's science departments are renowned for their research and the College in turn is rightly proud of its unusual success in drawing upon these departments for first-class instruction in the sciences. Indeed, this is one reason we place well over a hundred graduates in medical schools each year.

Yet all is not well. Many of the students who do not major in a science, and even some who do, spend four years here and graduate as scientific illiterates. This is no trivial matter, for science is the *lingua franca* of our era, and those unable to converse will, at best, be shut out from participation in great events to come. At worst, they will be unable to distinguish discourse from babble.

The stakes are high: a Columbia graduate should be able to distinguish intellectually between evolution and creation, astronomy and astrology, legitimate cancer research and holistic medical quackery. The alternative to scientific thought is fundamentalism—passively waiting for a mystical authority to tell you where the truth lies. We have ample reason, in the late 20th century, to fear the consequences of entrusting our destiny to fools, charlatans and madmen.

Why we're falling short

When I entered Columbia College in 1957, Sputnik's beep was about to be heard, even in Albany. I was one of many kids who had an extra bundle of money tacked onto their Regents' scholarship for agreeing to major in physics. Unlike most of my friends, I stuck with it. Like them, and like everyone else in my class, I took the core courses in Contemporary Civilization (CC) and Humanities.

From 1961 to now I have been engaged in that sort of biology where chemistry meets medicine; the molecular biology of viruses that cause tumors. My work has led me back to Columbia. I have been here for two years, happily tucked away in the red faïence marvel of Fairchild. Until I came back I had not taught undergraduates, so that when I did teach introductory biology last year, it was not an introduction just for the kids, but also for me. Between my teaching experience and my service on the College's Committee on Instruction—which has the formal responsibility to review every course offered by the College—I began to realize why scientific illiteracy afflicts so many of our students: the current science requirement provides our undergraduates with a peculiar and limited set of choices.

All College students are now obliged

A Columbia graduate should be able to distinguish between evolution and creation, astronomy and astrology, legitimate cancer research and holistic medical quackery.

to take "two terms of courses in the Natural Sciences." For the science major this is not a perceptible bump. For the non-science major, the eight science departments offer a choice of year-long courses tailored to the requirement—in effect, the least rigorous version of any given department's field is the sum total of science education for many students.

The premise of Columbia's general education philosophy is that students be exposed to a common body of texts in central academic disciplines. A core of writings in the Humanities and the Social Sciences are presented to each student, quite independent of his choice of major or eventual profession. The Natural Sciences, however, offer no such core curriculum. As a result no undergraduate, including the science major, is exposed to a systematic, searching examination of the premises of the scientific method, to the linguistic makeup of the sciences, or to the process by which a set of observations becomes, for a lesser or greater time, a "fact."

This is a deprivation of some magnitude. Never having grappled with the beauty, logic and rigor of science, our students continue to be vulnerable to the basest misuses of the jargon of science, and to a depressing, resentful dependence on scientists as incomprehensible wizards. They often fear both the process and the product.

The upheaval of 1919: a parallel

We don't have to look very far for a solution to this problem, because in 1919 a similarly felt need for a core curriculum led many senior and junior faculty in Columbia's social science and humanities departments to pool their efforts and produce that marvel of our College, the Contemporary Civilization program. A transdepartmental course based on a common text used by faculty from many fields, CC has thrived for sixty years.

The First World War challenged and finally ended the dear hope of many Americans that we were somehow protected from events on other continents. CC was a brilliant creative response to this challenge. The two-volume *Introduction to Contemporary Civilization in the West* assembled and introduced excerpts from hundreds of original sources. Although the basic CC text has been largely superseded by longer readings from many of the same sources, the underlying idea of the text has survived and is interpreted anew by every instructor and every class. I am quite convinced that now is the time to construct such a text for the sciences.

Since World War II the products of science have held us in uneasy thrall. The sciences have developed ways to understand the nuclei of atoms and of cells. They have learned how to construct electronic circuits almost as small and complex as the cellular circuits of the nervous systems of living things. They have explained and eliminated many diseases which were terrors in our parents' day. Such awesome results, from so many different sciences, have tended to turn science into a sort of magic.

But the language and the processes of science are not magical. They can be understood. It is inexcusable that for the want of a transdepartmental curriculum we fail to teach many of our students the fundamental vocabulary of scientific thought.

Building the new curriculum

The first hard step in constructing a rational curriculum for science at Columbia will be to identify those assumptions, rules, and ideas that are central to all sciences. Given these, the curriculum can be assembled as a mosaic of examples of these central processes, drawn from all the sciences. Here are my suggestions for four such processes, around which a general science course and text might be built:

1) *The centrality of error:* Only by actually examining data can a question be asked or answered with scientific literacy. Examination of data is not the same as looking at numbers. The critical difference is that data are never absolute numbers, but always have associated errors. Error is simply the measure of reliability of the number obtained by observation. Error is itself a number. The two numbers, observation and error, are inextricably linked, so that neither one without the other is of much use except to those who wish to clothe themselves in the quantitative costume of science in order to appear convincing.

The smaller the error, the more precise the datum. Two notions follow. First, where the observation is no better than its error not much can be made of either. Second, no data, and therefore no fact based on observation, can be absolutely free of error, or indeed absolute in any other sense. A good science builds while retaining this respect for error, and so avoids climbing out on any attractive, long, thin, observational limbs that may not actually be there.

We all hunger for absolutes, and since science produces such wonders, non-scientists often believe that the process yielding them must be one of absolute certainty. The temptation can overwhelm a scientist too. "Just say you are sure, no one will argue; other people say it all the time," goes the slippery path downward.

2) *Scales of Complexity:* The universe is built of atoms. The physical and chemical sciences deal with small assemblies of atoms. Biology intervenes when one examines molecules made up of more than 10^2 or 10^3 atoms (the exponent is the number of zeros after the one, thus, $10^3 = 1000$, etc.) Thereafter, life brings us molecules of all degrees of complexity from 10^3 to about 10^{10} atoms. The DNA of a chromosome, for instance, is this big. The bigger the size, the more chance for mystery, until at about 10^{15} atoms we meet the cell.

Because of its mystery, the cell separates two different kinds of science. Study of the behavior of single cells, or of multicellular structures (tissues, organs, people, roses, geese) deals in an atomic complexity so great as to be largely beyond analysis at the level of molecules. Indeed even one cell is too complex now, for the barrier to chemical analysis of molecules now stands somewhere around 10^8 or 10^9 atoms/molecule. It is a reasonable bet, however, that many of the unanswered questions of biology and medicine are waiting for a technology that will permit chemical analysis of large and macromolecular arrays. This barrier is likely to be constantly pushed upward. What are the barriers at the frontiers of other sciences?

3) *Ain't Disbelievin':* A common misuse of the trappings of science is to accumulate numbers, disregard their associated errors, and use the resulting counterfeit mess to justify a political decision already taken for political reasons. Scientists cannot do much to prevent this, although they might resist participating. A less common misuse, but one often engaged in by both scientists and non-scientists, is willful denial of what has already been discovered through science. Surely, this is magical thinking.

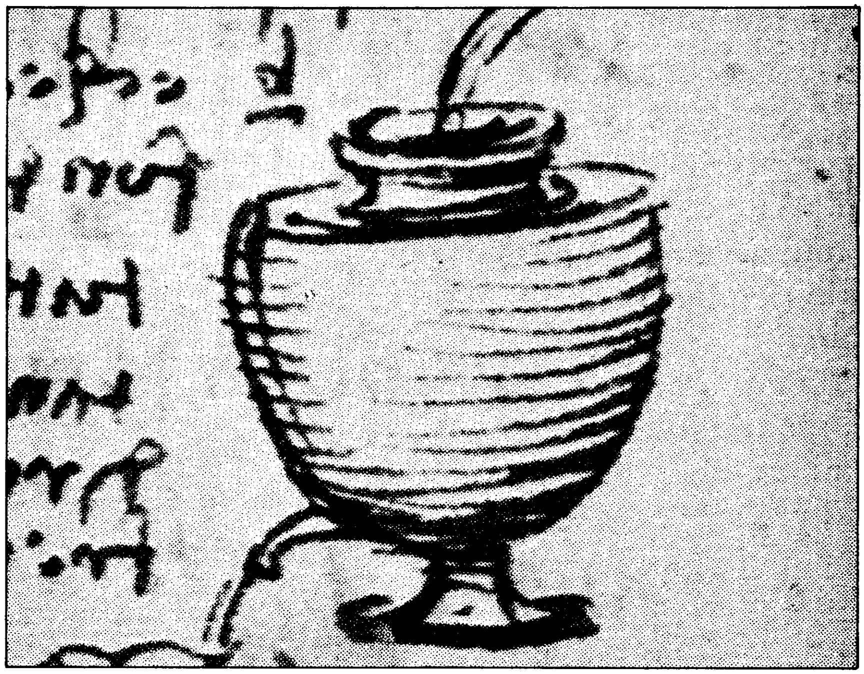
4) *Means and ends:* There is no scientific proof that the universe has a purpose. Yet most people have a strong sense that there is a purpose to the universe and indeed, some people have a strong ideological commitment which to them defines what the purpose is. What is the role of science in defining the boundaries of ethical behavior? For those people blessed with a clear sense of the purpose of the universe, that end often has been used to justify bizarre and even fatal means.

I have suggested these four themes as examples of central scientific processes; others might (and I hope will) be proposed. Teaching these themes will require a body of vivid, lucidly presented illustrations, which must be drawn from a variety of disciplines. The process of discussing and selecting texts with both sufficiently high quality, and what I would call commonality, will itself be one of the central tasks in forming a general education course in the sciences. For the purposes of discussion, let us call this new course Science in Society.

Developing a common text

Using CC as a model, the readings and case studies for Science in Society should allow students to confront directly the central issues of modern science. They must also be able to be employed by instructors from the various disciplines, as is true in CC and Humanities. In all instances, the quality of the texts themselves should be a paramount consideration. There is no reason why Science in Society should not be inspiring, as well as demonstrating the beauty of clear expression in a number of important ways.

As I envision it, the text might be a mixture of two types of material, the scientific essay and the case study. Martin Gardner's excellent anthology, *Great Essays in Science,* which presents examples of the work of 29 scientists as



varied as Charles Darwin, Rachel Carson, Albert Einstein and Ernest Nagel, could serve as a head start for a Columbia course. Different instructors will be able, of course, to draw different insights from these essays, as indeed will the students themselves. In presenting these texts Science in Society will essentially be continuing the work of Contemporary Civilization in setting forth "a certain minimum of our intellectual and spiritual tradition which a [student] must experience and understand . . . to be called educated," as Lionel Trilling said.

Case studies, on the other hand, may be more difficult to assemble. However, it has been done with great success by the graduate schools of business and the law schools, for example, and I think is worth attempting in the sciences. In case studies, students are asked to perform rigorous analysis and interpretation on very specific problems. No clear-cut answers are given or indeed presumed to exist. The point here is to involve students directly in the scientific mode of reasoning, and to work collaboratively with raw data. Again, no matter which field the particular case is drawn from, whether it is plate tectonics or particle physics, it should be teachable by a transdepartmental staff. (For students who may feel intimidated by vigorous quantitative exercise, I see no reason why the College cannot eventually offer a one or two point preparatory course as a pre-requisite, as we do in other areas.)

In covering 50 to 75 essays and case studies over two semesters, a student should be able to cover a great deal of scientific ground, in both method and content. While no one would claim that students will emerge with a specific expertise at the end of the course, nor would we expect an intelligent student to emerge as a scientific illiterate. I believe this can and should be a valuable course for science majors and non-science majors alike; it should substantially enlarge and update their common intellectual vocabulary, and it should even have beneficial side-effects in the quality of their reasoning and expression in upper-level courses both within and outside the sciences.

The practical problems

Science in Society should start off small. Smallness is a good protection against confusing sloppy thinking with diversity, and a good shield against total failure. Also, it will permit the selection of the most committed teachers and students. To begin with, I propose that those students doing well in the premedical and prelaw programs be asked to volunteer, with an eye toward their own future interests, for a semester in Science in Society.

A small program of such sections taught by faculty from different science departments would not at first change any requirements. It would permit a curriculum to be assembled by the most highly motivated senior faculty (as was done for CC during World War I). It would be challenging and fun to teach. And, if it were to succeed on the small scale, a body of readings and case studies would be assembled, section by section, that could be used by other teachers. Once freed from dependence on its initiators, a required Science in Society program would be on the way.

What would it cost?

I can barely imagine the horse trades that will have to take place among provosts, deans, chairmen and faculty before anyone will actually be permitted to teach such a course outside his or her department. In the sciences, there is little precedent for interdepartmental teaching. The general education idea intrinsically challenges the departmental structure, and it is expensive. The costs minimally are these:

a) Faculty time. Every new section taught will cost the University money.

b) Administrative commitment. Organizing such an enterprise requires assistance from someone willing to sit on all the cookie-pushing and paper-shuffling that could easily lead to the program's death by ennui. More importantly, without leadership and support from the highest administrators, the program will be orphaned.

c) Publishing time. Columbia is proud of the CC text. Science in Society should be built on such a text. Such a book requires a major financial and organizational commitment of its own.

Overall, it seems clear that this adventure will need the active support of Low Library, and the wherewithal to get started — either from Columbia or from other sources. I do think though, that the very novelty of the enterprise opens a possibility that is for us quite exciting: we might plan in advance to solicit teachers for this program from the entire faculty of Columbia University. That is to say, we might look to faculty at Barnard, the schools of Law, Medicine, Engineering as well as the members of our own College and Graduate faculties. Why not? The usual department boundaries would no more apply to them than to any of us.

We certainly have a precedent from the student's direction. The School of Engineering now requires CC and Humanities, and these students join College students in our core courses right now. For that matter, lots of Barnard students are in CC this semester, so Barnard faculty participation in Science in Society ought not to be beyond imagining. To me this would represent at least one concrete step toward providing equivalent educational opportunities to the brightest young people we can admit, without regard to gender.

Why bother?

This is a rough time for basic science in America. A populist pride in ignorance has always been part of our heritage, but it can get quite ugly when, as now, the economy springs too many leaks at once. We no longer can depend on friends who remain ignorant of what we do to support us in blind admiration or fear.

Perhaps the easiest tenet of the scientific process for a layman to understand is that the creative moments of science, as in music or the fine arts, do not respect national boundaries. Yet very recently, I myself was placed in a position of having to defend this notion against an attack from my scientific colleagues. As a member of a foundation advisory panel awarding postdoctoral fellowships in cancer research, I witnessed the serious proposal that the awards be restricted to Americans doing their work in America. The motion was defeated, but it was an astonishing debate to have suddenly cropped up.

I assume that we are entering an era when such confrontations will be common, and in which the debaters won't always be scientists. And then what? Who will speak for this invisible college of men and women trying to understand nature? No one will, who thinks we are no different from dangerous magicians, or who cannot understand what we do, how we think, or when we are right or wrong. Those of us who have chosen to remain with science for its own sake, for its own beauty, cannot any longer depend on ourselves alone to keep up the defenses against these and other temptations, threats and distractions. I can think of no greater set of allies, in the long run, than the future graduates of Columbia College.

We often speak with pride of Columbia's innovation and leadership in higher education, not in terms of capitulation to fashion, but in terms of setting standards. We have set forth a need for basic change in science education. Now we need to muster the will and the resources.

I share the impatience President Sovern expressed in his inaugural address: the time has come to "get on with it."

Humanists, Take Heart

by Pamela McCorduck

What Robert Pollack is proposing — a general education curriculum in the sciences — may benefit future generations of Columbia students. Is it too late for everyone else?

Fortunately not. For the humanist of good will, who regrets that his science education ended with poet's math, there is some excellent literature. Trained to understand humans, we can approach science — which, after all, is a human endeavor — through some of those who do science.

For example, there are scientists with both scientific and literary gifts who have written their life stories: Freeman Dyson's *Disturbing the Universe* is such a one. Jeremy Bernstein's *Experiencing Science* is a collection of his short profiles and essays, many of which first appeared in *The New Yorker.* They are elegant, decorous and refreshing pieces of literature, and Columbians will be especially interested in his profile of Nobel laureate I. I. Rabi.

Horace Freeland Judson, though not a scientist himself, has been highly praised for his *Eighth Day of Creation,* not only because it is a thorough history of modern biology, but because it gives such a sense of how science is done. If the heft of

Pamela McCorduck conducts a workshop in science writing at Columbia's School of General Studies. She is the author of two novels and numerous articles, and is now working on a scientific biography of Herbert Simon. Miss McCorduck, whose husband is Columbia computer scientist Joseph F. Traub, also wrote a history of artificial intelligence, Machines Who Think, *published by W. H. Freeman in 1979.*