

**Theory and Practice of Science:
The Place of Science in General Education**

Keynote Address

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Thanks for inviting me to lead us into a discussion of the proper place of science in general education. General education intends to broaden a student's perspectives and to develop empathy for other world views. Yet experimental science – a world view of the utmost importance for all Americans – can be quite peripheral or even absent from what passes for general education. While every college and university is stuffed with science courses, they result in singularly little sympathy or understanding of science for many if not most undergraduates. I would like to consider the barriers preventing general education from bringing science to non-scientists, and to propose some ways to do this right.

First, though, let me set a frame of urgency around what otherwise might be in the wrong sense an academic presentation. As I learned from National Public Radio one morning while preparing this talk, about 125 million persons are employed at some sort of job in our country. A full fifth of these are functionally illiterate. That is, about 25 million Americans hold menial jobs and the major block to their advancement is their inability to read and write well. What is the place of science in their lives? Either nowhere, or if anywhere, some place close by magic. Sealed off from books, they are also far from anything scientists think of as science.

Suppose we make a leap of faith and say that functional illiteracy is the result not of poor education, but of insufficient education. Let us assume, that is, that a typical high school education will still raise a boy or girl above functional illiteracy. I hope this is so. What science do high school students learn of science? Here are some numbers I gathered from Dr. Luther Williams, Assistant Director of Education and Human Resources of the NSF. He spoke to the New York Academy of Sciences last month on the need to train large numbers of a new sort of science teacher. Since his suggestions for curricular reform come attached to an annual budget of more than \$300 million, I'm sure you will all be interested in them, and I will return to them at the end of my talk.

Now, though, let me share with you the facts he gave us about the place of science in American education. In a word, that place is no place, even for the youngsters able to read and write well enough to advance in their jobs and careers. Most of them apparently avoid science as best they can. This country has about 13 million students in high school on any given day. Each year some four million high school sophomores receive their first serious exposure to science, usually through biology but sometimes chemistry, physics or environmental science. Some of these 10th graders will go on to college, others not. Once in college, some will retain an interest in science from their high school courses, but the majority will not.

Only 600,000 first year college students continue to show an interest in a career in science; that is, six of seven of those high school sophomores were lost to science three years later. The shrinkage continues unabated. Two thirds of the remaining college-level scientists lose their interest by the time their BAs are awarded, leaving 200,000 science BAs each year. Of these fewer than a third — 60,000 — enter graduate school in the sciences, and of those one sixth — 10,000 — receive a PhD in the sciences each year.

We are not here to discuss the proper number of scientists our country should be minting each year. But we must be concerned about the number, training and enthusiasm of each year's crop of new science teachers. The sharpest wedge in this progressive closing off of bright young people's interest in science occurs just as they are entering college. It happens just as they are deciding whether or not to join the ranks of our nation's teachers.

It hardly matters whether we are talking about K-12, or college teachers. The pool for both is made up of a large majority of young people who have just decided that science is not as interesting, nor as accessible, as they had thought a few years earlier; and a small and decreasing fraction of youngsters who still consider science as a possible career. Today it is all but impossible to find a PhD research scientist who has chosen to become a secondary-school teacher or the teacher of secondary-school science teachers. As a consequence few men or women who both know science and like it are likely to become teachers of science to the next generation of children. This negative feed-back loop is the root of our country's problems with the teaching and learning of science, at all levels.

The profound falling off of interest in and knowledge of science as high school students proceed to college also lies at the base of our topic for today. Science cannot become more important in general education if it remains unimportant to students. Their decisions, over and over again, to pull away from science, are signs of an old, deep cultural problem, the early separation of the intellectual worlds of scientists and non-scientists. General education in a liberal arts college is the proper place to bridge this great cultural divide.

My own experiences will serve as an example. To preface this brief personal history and to assure you that I am no theoretician, here is a story about our country's greatest living biologist. When I met her twenty years ago, Barbara McClintock was a small but powerful presence, wonderfully authoritative and magisterially frank. A decade later she became and at

ninety she remains today the first and only Laureate of both the MacArthur and Nobel Foundations.

One day I gave her two manuscripts, a report from my lab and a theoretical proposal I had thought of on my own, hoping that she would help me to get them published. She was enthusiastic about the research paper. The other she returned with a little note that read:

"Bob,

For my money this is just a big ego trip."

My education began in public schools in the borough of Brooklyn, in Coney Island, a ramshackle, dreamy part of New York City almost as far from the tourist's Manhattan as Asheville, North Carolina.

I had a good head for numbers. My parents – who had not been able to finish high school at all before getting their first jobs some 65 years ago – encouraged me to take school seriously and to be curious about the way things worked. The public school system pegged me as bright, and allowed me to skip 8th grade. There were no "AP" courses then, nor were there any good laboratories. However, there were clear and objective standards maintained by the State Regents. Our scores on the Regents exams were our teachers' benchmarks. Like our lunches, our curricula were stale, but filling.

My High School also had the benefit of about a dozen older teachers with PhDs, overqualified victims of the Great Depression. To me and my classmates they were a blessing, making our high school an intellectually strenuous place, and giving some concreteness to the otherwise abstract notion of higher education. One of these older science teachers convinced me to think of myself as a scientist.

The presence of these talented teachers was barely enough to make me think much about education in a broader sense. My parents were totally in the dark about colleges, let alone graduate schools. At the insistence of my teachers I applied to a few liberal arts colleges, among them Columbia. I came into Columbia thinking to be a scientist, and I left with a major in physics. But in between, thanks to a good general education program, I was taught how to put my work into a larger context.

In Columbia's "core curriculum" all first year students had to read a book a week from classics of moral philosophy of the West, from Plato to Marx, and book a week of literature of the West, from Homer to Dostoyevsky.

For me, general education was a set of precious, painful good-faith efforts to link an inner voice with a great book's arguments, to hear oneself think so that one could learn to think more clearly and analytically. The books gave specificity to difficult questions, ones that cut close to the bone of belief, ones for which there were no final correct answer. Some of these questions have stayed with me since then:

- Why does evil exist?
- Why must we die?
- How may we live fairly, equitably, with each other?
- How may we define and protect what is ours, without destroying the fabric of community without which we cannot enjoy any of our private holdings?

Science played no part in my general education. It was my chosen profession. I would have become a scientist without the core curriculum, but I would not have been made to see the links between my world and the larger world of events.

Not all scientists make the links between their chosen profession, their own work, and the larger questions of life and death. In large part because my education brought science together with a good set of general education courses outside the sciences, I did, and still do. By extension from my experience I would argue that the place of science in general education is to assure that science, and the ways scientists think and argue, become part of every student's exercise in learning to think for himself or herself.

It is essential that teachers know how to expose a future lawyer or political figure, military officer or corporate leader to a dose of my world, to protect her or him from the errors symmetrical to ones I would have made had I not been exposed to a good core curriculum in the humanities and in political philosophy.

These are the errors of believing

- that political decisions can be made in the absence of clear observation,

- that facts can be dispensed with if they are discomfiting, and
- that irrational certainties can be used as reliable indicators of proper action.

To avoid propagating these errors science teachers must learn what science is, how it is practiced, and how it connects to the large, unanswerable questions central to general education. Here is the great physicist, Richard Feynman of Cal Tech, on the importance of this fundamental link between the practice of science and the purposes of general education:

"It is our responsibility as scientists, knowing the great progress which comes from a satisfactory philosophy of ignorance, the great progress which is the fruit of freedom of thought, to proclaim the value of this freedom; to teach how doubt is not to be feared but welcomed and discussed; and to demand this freedom, as our duty to all coming generations."

How can we make sure that general education includes "a satisfactory philosophy of ignorance?" By opening up three doors. These are

- the cultural barrier of a general fear and antipathy to science in our society,
- the political barrier of a misuse of general education, and
- the academic barrier of resistance to change on the part of many science departments.

Let us consider these impediments in order.

The cultural obstruction to science entering general education properly has to do with the way science is seen by the general public. According to too many news magazines, TV documentaries, soap-operas and movies, scientists pursue magic powers as white-coated practitioners of a pagan religion. They obey only their own arcane rules, and then only to be first to uncover some mystery of the universe that would be better kept hidden. But since these discoveries can lead to new products of great, if morally ambivalent, value, the public cannot totally disregard their efforts. Public interest in science from this perspective is reduced to a somewhat risky set of deals with a somewhat shady entrepreneur.

Nor is this pervasive anxiety baseless. Science and scientists can do incalculable damage. Twice in the first half of this century the practitioners, methods and rhetoric of science were made into myths to be used by cynical regimes with disastrous consequences.

Seventy years ago the Soviet Union became trapped in the myth that a science of history with predictive powers required social engineering in every corner of life, no matter how private. Until recently scientists there have had to choose between providing support for this myth, or banishment and death at the hands of their government's internal security services.

In the same period the great medical and genetics laboratories of Germany contributed to a nationalistic myth of race that led before its collapse in flames to the deaths of millions of innocent people. Their only crime was their failure to meet carefully quantified, scientifically defined norms.

In Russia, Poets say what scientists and others cannot. In the early 1930s the great Russian poet Osip Mandelstam –later arrested and killed by the NKVD for writing a poem on Stalin – wrote of his country's fundamental error in turning to "science" for solutions science cannot provide:

"One cannot launch a new history – the idea is quite unthinkable; there would not be the continuity and tradition. Tradition cannot be contrived or learned. In its absence one has at the best, not history but 'progress' – the mechanical movement of a clock hand, not the sacred succession of linked events."

Are we, now, in this country, susceptible to the science-as-myth? Of course. For us, it is the myth of invincibility, of an escape from the historical limitations of other cultures and civilizations. This myth supports us in our unparalleled power and authority over the resources of the planet. We consume about ten times more of the world's energy resources per capita than the rest of the world's peoples, and we show no signs of backing off from our overindulgence. We share some responsibility for the myth of never-ending fixes, and we have an obligation to say so, if only to keep from being scapegoats should this myth about science turn sour.

A second, political block to the introduction of science in general education is the misuse of general education to indoctrinate students instead of teaching them to think. The intellectual abuse sometimes begins with the notion that we are obliged to agree upon the high points of our culture and civilization, because together they define us as a nation or a culture. At other times it begins with the opposing wish to bring down the edifice of a national culture and replace it with the monuments of a set of approved subcultures.

In either case indoctrination follows when lists of books, pieces of art and music, political tracts and religious credos are assembled and used as the source of a set of facts, ideas and memories that must be learned in one particular way. Universal matters of life and death rise above particular times and places in world history, above even our own national iconography, important though it may be. When the asking of questions is less important than the memorization of lists, general education has failed, and political correctness has taken its place.

The same texts and cultural artifacts can be found in general education programs that encourage questioning and those that do not. This has led to considerable confusion. The differences show when one examines how the texts and such are used. By the first definition, they are sources of nuggets of information to be memorized. By the second, they are anvils against which each student is to bring the hammer of his or her own ideas and expectations, the better to forge an individual set of beliefs and standards, not one either predictable or demanded in advance by the course.

Science belongs with the Arts, Humanities and Social Sciences in proper, non-doctrinaire General Education not for the facts it can impart, but because the work of scientists is a path into the large questions that define our culture. Science springs from the same human impulse as do music and philosophy, the impulse to create order from chaos, to capture a piece of the universe's truth by sheer will and creativity. Precisely because scientists can change the world for the rest of us as they ask their unanswerable questions, science in general education science can and should deal with the same deep, unanswered questions found at the center of the other portions of a proper general education curriculum.

As I have already noted, some poets seem to be able to see science for what it really should be. Many years ago I corresponded with the late British poet Robert Graves. In one letter he wrote:

"Very many thanks for your letter which meant a lot to me, as you will realize. Poets and physicians are closely allied in thought. Diagnostics and cure (truth and love, in essence) belong to both professions. In fact I find real doctors far closer to me in spirit than musicians or painters or sculptors. By 'doctor', of course, I include all scientists who are not rountineers of science, but have hearts and minds and are finding out the relations between mind and its physical concomitants ... "

The third obstacle to science in general education is neither political nor cultural. It is the purely academic resistance to general education as such in many science departments. The essential properties of the science component of a solid general education curriculum are that

- it should be interdepartmental, or more properly transdepartmental,
- it should be taught by practitioners of science, and
- it should offer students an opportunity to debate and discuss the philosophical, historical and methodological contexts of current research.

The current structure of university science departments makes each of these hard to get and harder to maintain. Interdepartmental courses in particular will never be easy to organize, or to sustain, so long as salaries, promotions, office, lab space and teaching assignments all flow to faculty from the chairs of separate departments.

The nation-states of Religion, Classics, English, Comparative Literature and Languages have been able to agree on a common market of the Humanities. The kingdoms of Economics, History Political Science and the like have the political maturity to band together for their common good. The departments of Physics, Chemistry, Biology, Psychology, Astronomy, Mathematics and Computer sciences are each a separate and sufficient world to their faculties. Few science departments anywhere are quite ready to acknowledge their membership in even a loose academic Federation of Science. As a chemist once said to me, "I don't teach science, I teach Chemistry." And he did, brilliantly, but irrelevantly to the hundreds of college students who, fearing and loathing the way chemistry has to be taught to chemists, never had the chance to meet him.

The moat around each science department cannot be easily crossed by student, professor or dean. It is a permanent fiscal high tide, held in place by the full moon of government funding. Research supported by outside funds permits scientists to live better than their colleagues in the Departments of the Humanities and Social Sciences. (Economics is an honorary Science in this regard, since academic economists will, as expected, make use of any model that maximizes their income.) Federal procedures allocate money for scientific research by field, usually through peer review. These funds pay for the research itself, of course, and for the visibility it may bring to the institution.

In many universities a professor may claim as well one or two extra months of salary from a grant, usually for the summer. Through the much-maligned and misunderstood mechanism of Indirect Cost Recovery, outside grants pay for a variety of legitimate, research-related expenses – departmental computers, secretaries, faxes, copying machines and the like – that make a science professor's life incrementally easier than it would otherwise be.

Given these facts of life, no one should be surprised to find that scientists have organized life on their departmental islands so as to keep up the tidal flow of outside research grants. Steeped in the ethos of peer-reviewed granting, researching, promoting and hiring, many regard themselves first and foremost as citizens of their Departments, and only where convenient, as citizens of their college or university. As a direct result of this enlightened self-interest, interdepartmental, general curricular concerns rarely get proper attention.

Scientists look puzzled when a well-meaning colleague or dean asks them to put some extra time and effort into general education. It brings them no grants, adds not a bit to their research capability, and requires them to teach outside of their expertise to students who by definition will never become their intellectual offspring. They enter such discussions open-minded but puzzled, then become amused, and then bring the conversation to a close by getting back to their real work.

Here are some suggestions on how we may begin to establish a proper place for science in the general education curriculum.

As an antidote to the first, cultural barrier, nothing I know of beats going public. Scientists must tithe their time to explain themselves to the taxpayers who support their research. This symposium is a good start. Campuses large and small all share one useful property: they have good places to hold public talks and demonstrations, discussions and debates, about science and public policy. Those that do none, should begin. Those that do some, should do more.

With regard the second, political barrier of misplaced enthusiasm for a doctrinaire variant of general education, my suggestion is equally simple. This barrier is made by our colleagues, and we should be able to take it down through examples of principled discourse. We must stand up and be counted at departmental and faculty meetings. We must insist on the primacy of free-thinking, non-ideological, non-formulaic discourse, and on the centrality of

respect for ideas different from our own. We must also be more humane, acknowledging the links between our work and our beliefs, our work and our feelings, and most important, between our work and our fears.

The third, academic obstacle can also be overcome by an investment of our time, but some start-up money will be needed here as well. Let me give you an example. With the help of various foundations we have been able to enlist Columbia faculty of many departments in an interdepartmental general education course that has been taught regularly for a decade. This course uses papers from physics and biology as its only texts; there are no textbooks. Rather than teach to a typical, department-based course curriculum, beautiful, rigorous examples from physics and biology give us a chance to read and discuss good science with our students. Our job in this course is to bring the students enough math to permit analysis of the data in the papers they read, and enough background in physics or biology to provide a context for the papers.

The core of the course is the papers themselves, in all their knotty, idiosyncratic complexity and beauty. Routinely, a close reading of research papers leads the class to discussions of their historical and philosophical ramifications as well. This course works well, and insofar as it meets Columbia College's science requirement it may be said to be part of a comprehensive general education curriculum. It is however cumbersome to teach, because no professor is asked to teach outside of his or her field. It does not share the singularly pleasurable attribute of a true general education course, that is, the amateur standing of the professor as he or she leads the discussion. Still, it is an example of how to break out of the curricular, if not the departmental, barriers to general education in the sciences.

Scientists active in their laboratories cannot be asked to create and maintain such enterprises out of good will alone. We need the leaders of our colleges and universities to articulate a vision of the University that includes at its center a commitment to general education, and to back that vision with reasonable resources. Without such a jump-start, the other interests that lie at the heart of a science department are simply too strong and too utilitarian to be budged. The problem is, all too often we are managed, rather than led. Here is how a great academic leader, the late A. Bartlett Giamatti of Yale, distinguished between the two:

"Management is the capacity to handle multiple problems, neutralize various constituencies, motivate personnel Leadership on the other hand is an essentially moral act, not—as in most management—an essentially protective act. It is the assertion of a vision, not simply the exercise of a style: the moral courage to assert a vision of the

institution in the future and the intellectual energy to persuade the community or the culture of the wisdom and validity of the vision. It is to make the vision practicable, and compelling."

[from NRC, "Fulfilling the Promise: Biology Education in the Nation's Schools", National Academy Press, 1990]

The in-house leadership we deserve will have to be backed in turn by leadership from our colleagues in the Federal research establishment. For the sake of better science education, and to assure that tomorrow's science teachers will be prepared to teach tomorrow's science, the paradigm of government funding of academic research will need to be redefined.

The most direct way for outside granting agencies to shake up the science departments and to capture talented scientists for teaching in interdepartmental general education programs, would be to pay them extra to do it. A precedent for such a subsidy exists. The NSF and the Hughes Foundation help to cover the costs of faculty who are willing to take undergraduates into their laboratories for summer or term-time research. The NSF gives a grantee this money more or less for the asking, as a supplement to a regular research grant.

Practicing, funded lab scientists who were willing to put in the effort to teach non-science students ought to get some support for their research in exchange. Here are some suggestions for how to do this:

- Funded scientists could be invited to apply to the NSF or NIH for a month of summer salary for course preparation. Those already taking this money from their grants should be to turn this curricular stipend over to their research.
- A similar arrangement should be worked out to provide summer salary for funded research science faculty to produce short, inexpensive textbooks and sets of readings for use in general education science courses.
- Training grants for PhD programs and for postdoctoral fellowships in the sciences should include a supplementary stipend for teaching non-scientists.
- Research scientists who teach in general education courses should be able to apply to their funding agencies for additional graduate student support.
- Secondary school science teachers ought to be given the opportunity to spend a summer working in a research laboratory. At Columbia the Hughes Foundation

supports such a program, headed by Dr. Sam Silverstein, Chairman of Physiology. This program has already send dozens of high school science teachers back into the classroom with a new, strong, realistic commitment to teach science well.

Have I just merely jerked my liberal, tax-and-spend knee? I don't think so. In the private sector it is common to find a few percent of profits plowed back into research and development. I am talking about plowing a small fraction of the basic research budget back into research on, and development of, ways to assure a next generation of scientists who will have the support of a scientifically well-educated citizenry.

The budget for basic research from NIH and NSF alone is in the 10s of billions of dollars. Summer support for a senior professor comes to about 10 thousand dollars, including fringes and indirect costs. About 10 thousand new research grants are issued each year. If one in ten professors getting new grants also could also receive a summer supplement for general education purposes, the additional cost would be about 10 million dollars a year. This is about 1/10 of 1 percent of the grants budget, or one volley's worth of Patriot missiles, each year. Either way, it is no giveaway. It is a prudent way to to bring the next generation of science teachers and students out of the 19th century before the 21st century begins.

It is time to return to Dr. Williams and the NSF. The NSF is willing to act – that is, to spend serious money – to improve and broaden the teaching of science at all levels. Last month the National Science Foundation announced it would go into partnerships with ten States. Together these ten states plan to spend \$150 million over the next five years to retrain teachers and revise curricula in the sciences and math, for schools and colleges, or for K-16, as the jargon has it.

Proper general education in science should be an important part of the NSF incentive, if for no other reason than that general education courses in science are likely to be the only college or university science courses taken many undergraduates who then choose to become teachers. As a stopgap the NSF plans to support programs that retrain high school teachers and give them exposure to science as it is practiced in University laboratories. This is an effective first step. At steady-state, though, teachers-to-be should engage the intellectual processes that underlie good science while they are still in college. When they are able to do so, science will have found its proper place in general education.

One last thought, about political correctness. We have all heard a great deal about the rise of PC from the Left. It is wrong to impose ideological constraints on faculty and their courses in the name of cultural diversity. We do not hear so much, though, about an older problem, political correctness from the Right. It is also wrong to assume, privately or publicly, that the building of our civilization is, for want of a better phrase, a "white man's burden." In terms of who does science, political correctness from the Right sees everyone in a proper place in the social order, and sees no problem with a society in which scientists are greatly disproportionately male and white.

Both brands of Political Correctness work against some basic truths about our country:

- We are a uniquely diverse nation.
- We have an obligation to preserve a flat field for discourse among the many ethnic and religious groups who have come together as American citizens over the centuries.
- Science, in particular, should have no racial or religious component and should be equally available to youngsters of all backgrounds.
- The fact is, that it is not: white male science professors have far too few African-American, Asian-American, Latin-American and female colleagues.
- We should own up to our obligation to move over and make room at the bench for these fellow citizens.
- General education in science is the one obvious but largely untested way to show the youngsters of this country that science is in fact open to people of all backgrounds.
- For that reason alone it deserves to be at the center of our college and university curricula.