The priority need is to develop a systems analysis with heart that society can rely on to choose between possible technologies.

Murray Gell-Mann

How scientists can really help

Last fall I had the honor of speaking at the dedication of a new physics building on the University of California campus at Santa Barbara. As I arrived for the occasion, it struck me how lucky the physicists at Santa Barbara are to be living and working in such a glorious place. The day was clear and I could see the mountains, which contain the surviving frayed specimens of the majestic California condor, and the channel, with the islands on the other side. I had been sailing in the channel and had seen it sometimes sparkling in the sunlight, sometimes shrouded with fog, full of dolphins and sea lions. The campus is built on what used to be my favorite bird-watching place in Southern California, with its curlews, godwits, and phalaropes. Now, for the males of our species, it is a favorite girl-watching place. In any case it is bustling with young Californians presumably seeking knowledge and wisdom, and some older people who are supposed to be able to impart such things.

I think a campus like Santa Barbara is a very suitable place indeed to work on science, because for me the two things are inseparable, the love of the beauty of Nature and the desire to explore further the symmetry and subtlety of Nature's laws. I have an innocent view of pure science, of inquiry driven by wonder and curiosity, and the thrill of learning enough to make predictions that are astonishingly fulfilled. People have had in times past innocent views also of applied science and of engineering—of conceiving and building, based on scientific understanding, devices that are to enhance the life of man and free him from slavery to toil, hardship, ill health, and early death.

But somehow these are not the typical visions of today. Some of our most successful institutions are in trouble, under attack, and even despised, sometimes by intellectuals and frequently by educated young people. Universities are being challenged in many countries. In our country, in particular, science is in ill repute, together with such gigantic and impressive feats of engineering as the manned flight to the moon. Furthermore, scientists and engineers are finding themselves occasionally unemployed; funds for research are sometimes hard to find; and particularly the flow of brilliant students into these fields is declining.

Of course, considering the rapid exponential growth in a decade and a half, some leveling off of the effort in science was inevitable. The growth of science would have to follow an S-curve as so many other things do when exponential rises begin to saturate resources and talented people. However, we deal here in fact not with an S-curve but with a truncated S-curve, suddenly become flat and even declining.

And that is not all. We are seeing among educated people a resurgence of superstition, extraordinary interest in astrology, palmistry and Velikovsky; there is a surge of rejection of rationality, going far beyond natural science and engineering. In my opinion, some of the adverse reaction to science and engineering and even to rationality is understandable.

There are the unfortunate effects of carelessly deployed or carelessly diffused technology, the recognition of massive unintended adverse effects on the planet and on its living things, the possibility of massive unintended effects on human individuals and on our social institutions from already existing technology and especially from things that we can see dimly in the future. These effects are interpreted, and quite correctly, as being connected with a kind of narrow rationality, that takes into account in decision-making only things that are very easy to quantify, and sets equal to zero things that are hard to quantify. But sometimes those latter things are of paramount importance, like beauty or diversity or the irreversibility of change, in the case of the environment; like privacy for the individual; for our institutions, an analog is the quality of giving people the feeling that they are in control of the rapid change that is occurring in their world. We see narrow rationality in the making of some government decisions of great importance. We see facts and figures marshalled in huge arrays that have failed somehow to include inputs from common sense or from human values.

There is also, especially at the universities, a tendency to indulge in thinking that is narrowed by exclusive concentration on a single discipline, and the fear of being called bogus or arrogant if anyone sticks his head out of his own

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building to comment on someone else's problems.

Let me mention too the widespread failure to explain the overwhelming relevance of learning, of understanding, of analyzing, of using reason to approach the world and its problems, and the absolute necessity of using science and technology no matter what we want to do with our technically complex world, even if we want to make it less complex. "Learn this because I tell you to learn it, memorize pages 23 to 54," so often is what we say, instead of explaining how learning helps us to be complete and effective human beings.

I believe that narrow rationality, pervading government, universities, industries, and other parts of our national and even international life, is provoking a wave of insufficient rationality. Youngsters tired of the tyranny of badly programmed computers, and of people who act like badly programmed computers, are turning to tarot cards and charlatans.

What scientists can do

Are we destined to be squeezed to death between bureaucratic automata on the one hand and superstition or raving on the other? I hope not, and I think we can all work together to strengthen the cause of humane rationality, an approach to the world that utilizes reason and an understanding of Nature's laws and an enthusiasm for invention while at the same time celebrating the great importance of human, of natural, of spiritual values difficult to subject to rigorous analysis, an approach that tries to reconcile all of these in planning the future.

We can see a need for humane rationality and, in some cases, an opportunity for scientists to participate in a number of activities, some of which will require increased support from our society if they are to succeed.

First, activities requiring the cooperation of people from many disciplines, including engineering, natural science, social science including economics, law, medicine, as well as representatives of government at various levels, business, and the concerned public, to plan for a wiser use of our awesome technical capabilities. Some of this work can be done under the

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rubric of technology assessment and control—trying to understand in advance some of the human, social, and environmental consequences of the introduction of new technologies or of the widespread diffusion of existing ones (which can be of much greater importance even than the introduction of new ones on a small scale), and then trying to influence society to create positive incentives for the introduction and diffusion of those that seem on balance to be beneficial and to create negative incentives against those that seem to have dangers or unpleasant features that outweigh their benefits.

We needn't consider only this general class of proposed work, but also other ways of slicing the subject; for example, one can consider strategic planning for the environment, trying to take into account the complex interrelationships among human industrial activity, our air and water, the creatures that share our planet, and the quality of human life, recommending courses of action that can reconcile prosperity (narrowly defined) with quality.

Whether the approach is through technology assessment and control, or through environmental management, urban planning, or other rubrics, there is a clear need here for the cultivation of humane rationality, because we have great technical complexity in all of these questions combined with an intimate involvement in conflicts of human values. These conflicts must be settled ultimately by the political process, but experts may nevertheless have a great deal to say about the differing relevance of various kinds of values to the problems at hand. Some systems of values may be far more appropriate to the situation than others.

The technical complexity means that we need something like what is called systems analysis, to take into account all the factors. As a familiar example in the environmental field we can consider the problem of controlling Southern California's photochemical smog. The contribution of automobiles to this problem was recognized more than twenty years ago, when my colleague Haagen-Smit showed how unburned hydrocarbons and oxides of nitrogen were both required for the photochemical reactions which produce smog. It was decided very early to try and control hydrocarbons as being easier. It was also decided at the same time by the other authorities that health problems might be associated with the existing emission levels of carbon monoxide, which has no known connection with smog. Regulations resulted curbing both carbon monoxide and unburned hydrocarbons. The natural response of the automobile industry was to raise the flame temperatures in engines to maintain the so-called high performance of cars, thereby increasing the emission of the oxides of nitrogen and largely cancelling the benefit of the regulation of hydrocarbons. If we include the increase in car population, we find that smog has not been reduced at all. We may hope that in the coming decade we will do better with a different strategy of regulation.

One can look at the problems of generating electric power, which are even more complex than the smog problem, and see how involved the technical issues are.

Clearly we do need something like systems analysis, but can we stand to live with much of what now passes for systems analysis, in which people are reduced to personnel and wild creatures to resources, the places where poor people are to live become dwelling units, and with all of the calculations that are associated with this kind of jargon? With anything hard to quantify set equal to zero, a highway can be driven straight through a neighborhood or through a rare wilderness because

"We want to feel free to [develop] technologies that we can then renounce as inappropriate on total human appraisal"

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there is no reliable quantitative measure of damage to set against the increased cost of running the road around the outside. Systems analysis, besides, has so often been used to justify unwise decisions in the field of national security, on which I need not comment further.

We need, instead, systems analysis with heart, and scientists, along with many other kinds of people, can help to develop it so that we can recommend to society a set of incentives for the humanely rational use of technology.

Second, suppose we are now indeed to abandon the old principle of building anything we know how to build because we know it can be done, if only the cost in conventional and easily quantified terms can be kept within bounds. Suppose we now try to include also the cost in human, social, and environmental terms and to deploy, as I believe we should in the future, only a smaller and smaller fraction of what is technically possible, according to the principles of technology assessment and control. This is what I call the "narrowing cone."

If indeed we make use only of a narrowing cone of the technical possibilities generated by science and engineering, does that mean that we need less technology and less applied science? I claim it means we need a good deal more technology and more applied science, and in the long run, more pure science as well. We want to create, for example, incentives for the development of more modest technologies, less intrusive as far as the environment is concerned and as far as the human individual is concerned. Technologies like this could be doing some of the necessary industrial tasks that are performed today by technologies that are too much of a nuisance. We want to create incentives for the development of counter-technologies in order to repair, when it is reversible, the damage that technology has done. We want to create attractive employment for people whose work has to be curtailed or abandoned because it is too destructive or too unpleasant for the rest of us. In short, we need a great deal of science and technology in order to provide a much longer menu of possibilities from which society can select the few tasty and nutritious dishes that are indicated by the technology assessment process. We want to feel free to do research on and sometimes to develop, sometimes even to bring into the prototype or initial production phase, technologies that we can then renounce as inappropriate on total human appraisal. Curiously enough, this is an area where our defense establishment seems, unwillingly or unwittingly perhaps, to have done something right, and to have been roundly condemned for it by nearly everyone. I would like to see our civilian sector develop a wide variety of technologies, and then, as the Pentagon has so often been condemned for doing, with apparent but not real wastefulness, to throw most of these technologies away as being unsuitable on careful consideration.

Third, it seems to me that right now science and technology are being underutilized in a wide variety of immediate civilian tasks of great social importance, including the development of health care systems, transport systems, fire prevention, product evaluation for consumer protection, housing for the poor, effective and gentle police work, and many others. None of these is like sending a man to the moon, because in greater or lesser degree they are all involved with social problems, local laws and regulations, political conflicts, and the feelings or preferences of large numbers of individual people. Still, I think we should make a beginning of trying to harness science and technology to these tasks, and to employ interdisciplinary cooperation and humane rationality in the course of the work. I think, as long as these jobs are being neglected, we cannot speak of any overproduction of scientists and engineers.

Fourth, in an age of great technical complexity and of impressive scientific advances, we scientists and teachers have largely failed to communicate to the public, to students not specializing in science, and even to students in technical disciplines outside of our own, the meaning and importance, let alone the beauty and excitement of science. Do we expend a great deal of effort in trying to raise the standards of science and technology journalism? When we teach science courses for the arts or humanities students do we communicate successfully the world view that is emerging in molecular biology, or in geophysics, or in particle physics, or in astrophysics? Do we explain what real research is like, and introduce the student to life and work in the laboratories nearby? Do we convey to the students the dialectic by which scientific discoveries are made and recognized? Do we explain the relevance of scientific and technical developments to political decisions and to the life of every human being on the planet? Or do we rather have the students memorize a few of the laws from an elementary physics book and regurgitate them on an examination?

Fifth and finally, the most important contribution that we scientists can make is to go on with our own research and teaching in pure science, to follow where curiosity leads and to take the small steps that culminate, once or twice in a generation, in those great universal syntheses like quantum mechanics, relativistic gravitation, the genetic code, the theory of the evolution of the stars. These works of pure science are among the noblest monuments of our culture and I believe they will be remembered when much of our petty bickering of today is forgotten. Let us rejoice in the small contributions we are able to make to these historic advances in man's understanding and appreciation of Nature.

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This article is adapted from a lecture presented at the dedication of the Physics Building, University of California at Santa Barbara, 26 October 1970. □