Science and Technology in a World Transformed

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My father was born in 1900 and died in 1984. In those years, he participated in one of the most drastic transformations any species has ever experienced. It is difficult to comprehend the extraordinary changes that people have witnessed in this century as a result of advances in science and technology. We are so deeply embedded in the present that it takes a difficult mental effort to comprehend the time scale of human life on Earth and the recency of the kind of world that we live in now. Human ancestors have been separate from the apes for about 5 to 10 million years. For almost that entire time, there were fewer than 1 million people on earth, subsisting by hunting and gathering in small, nomadic groups. Agriculture and large, settled populations have existed for much less than 1 percent of that epoch, and our technical world has been present for a mere moment in the time scale of human evolution. The way we live today is, in many important respects, a novelty for our species.

Summary. In this era of rapid, far-reaching transformation, our way of life is in many respects a novelty for our species. Opportunities arising from profoundly enhanced capabilities in science and technology are felt in every sphere of life from health to communication, yet each advance has side effects that take time to appear. Grave institutional inadequacies are manifested in the prevalence of totalitarian governments, proliferation of devastating weapons, failure of educational institutions to prepare most people for the modern world, failure to use what we know to prevent damage to a large proportion of the world's children; and the weakness of international institutions to deal with global interdependence in the face of persistent ethnocentrism and prejudice. The American scientific community can usefully become more deeply engaged with these great problems.

Our ancestors—prehuman, almost human, and distinctly human—lived in small groups in which they learned the rules of adaptation for survival and reproduction. They used simple tools to cope with the problems of living and struggled to obtain more control over their own destiny. For the most part, they were vulnerable to the vicissitudes of food, water, weather, predators, other humans—whatever nature might bring. Their world began to change with the onset of agriculture about 10,000 years ago. But the most momentous changes occurred with the industrial revolution two centuries ago, and above all with its pervasive implementation in the 20th century.

Much of the technology that structures American lives today, in ways we largely take for granted, is of extremely recent origin. In 1900 there were few automobiles or household telephones; motion pictures were just getting under way; there were no household radios, no airplanes, no televisions, no computers. Today it is almost impossible to imagine a world without these technologies—and in this country, without their presence everywhere. What a difference a century makes—indeed, even a decade as events move now.

Opportunities and Complications

The opportunities arising from our profoundly enhanced capability in science and technology are visible in every sphere of human life—in medicine and public health, in agriculture and food supply, in transportation and communication, and elsewhere. Every advance has brought side effects—like a new medicine whose benefits are clear but whose complications take considerable time to appear. But complications there are: extreme population growth in much of the world, drastic urbanization with its crowding of strangers beyond any prior experience, environmental damage, resource depletion, the immense risks of weapons technology, and new patterns of disease—all are largely products of changes that have occurred only in the most recent phase of human evolution. We have rapidly changed our technology, our social organization, our diet, our activity patterns, the substances of daily use and exposure, patterns of reproductive activity, tension-relief, and human relationships. These changes are laden with new benefits and new risks, and the long-term consequences are poorly understood.

Many of the technological changes are exceedingly attractive since they free our species from hardships and dangers; they provide gratifications that were beyond reach at least for most people in the past. In many respects, ordinary citizens live today as kings of an earlier time never could.

The automation of the household has drastically reduced the requirement of physical labor at home. Its social implications have been far-reaching. Similarly the revolution in telecommunications has come close to making this country a single large community in some respects and may one day have a similar effect on the world as a whole.

Technological innovation is now associated with far-reaching and extremely rapid changes in the nature and scope of work available in this and other countries. The pervasive mechanization of work appears to be tangible on the horizon, not as a distant prospect, but as a powerful current gathering momentum and affecting the entire economy in far-reaching ways. Benefits in productivity are clearly visible. Concomitant social dislocations are not as visible but are as likely to occur.

Growing Pressures on Resources

There are in many parts of the world today strong tensions between population pressures and available resources. These tensions have explosive potential within countries and also for international conflict. It has become a matter of our enlightened self-interest as well as of decent human concern for us to try hard to understand our species in its world-

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wide interdependence, paying just as much attention to the Southern Hemisphere as to the Northern Hemisphere. For our own sake as well as theirs, we need to strengthen our ties and work cooperatively with people in developing countries toward the reduction of poverty, ignorance, and disease.

Since the sciences provide our most powerful problem-solving tool, it is essential that we bring their strengths to bear on these problems to the maximum extent possible. The task requires an intensive effort now to learn what can be extracted from the efforts at economic and social development during the past several decades, sorting out failures from successes, looking for strengths on which to build future efforts of practical value.

The problems that face modern industrial nations are related to sociotechnical conditions that have appeared very recently in the evolution of the human species: the magnitude and rate of change make it difficult for us to devise and implement solutions to these problems. In developing countries, the shift from old to new ways has occurred even more rapidly, and change has been partly imposed from outside. These nations confront exceedingly difficult problems. Across much of Africa, Asia, and Latin America, explosive population growth and abject poverty have contributed to extremely severe health problems that stand as an enormous obstacle to sustained development and social progress. Their burden of early death and long-term disability is exceedingly heavy. Infectious diseases take the lives of a great many infants before they reach 1 year of age and handicap for life many of those that survive. Susceptibility to a wide range of diseases is heightened by the marginal character of subsistence.

Global Interdependence

This set of facts raises ethical questions for countries with strong scientific capability. In recent decades, the United States has given little attention—in research, education, and practice—to some of the most important disease problems in the world today. How can we and the other more developed nations help improve health in developing countries? One way in which we are especially able to help is through research—including capacity-building in developing countries so that they can tackle their own problems. Priority areas are: (i) epidemiological assessment of specific needs; (ii) applying molecular biology to parasitic diseases; (iii) devising a wider array of fertility-control methods with special reference to cultural acceptability and feasibility of use; and (iv) clarifying relations of health and behavior, with special reference to breast-feeding, nutrition, child care, sanitation, water use, and family planning. What is fundamentally needed is a heightened awareness within the scientific community of the opportunities that exist, since even a modest shift of attention to such problems could yield major benefits.

Difficult as these problems are, and crying out for a larger place in the work of the scientific community, another aspect of our global interdependence is even more urgently in need of attention. The overriding problem facing humanity today is the threat of nuclear holocaust. Humanity's capacity for destruction has radically outstripped its institutional capacity to control intergroup violence. That violence is rooted in the nature of the human species. Mass expression of violence—war, terrorism, and genocide—persists throughout the world, and no people should be considered incapable of it. But the invention and deployment of nuclear weapons represents a qualitative break in the history of violence. It is now possible to destroy human life on Earth. Both the United States and the Soviet Union probably have the capacity to do that, or at least to make the human condition unbearable. In 1983, new evidence of the incredible devastation—immediate, long-term, and permanent—of nuclear war was brought to light.

Former Secretary of Defense Harold Brown points out that in the first half-hour of a nuclear war there might well be 100 million deaths each in the United States, in the Soviet Union, and in Europe. It is plausible that a billion people would die in just a few weeks. In point of fact, there is nothing in our history as a species to prepare us to comprehend the real meaning of such devastation.

Human societies have a pervasive tendency to make distinctions between good and bad people, between heroes and villains, between ingroups and outgroups. It is easy for most of us to put ourselves at the center of the universe, attaching a strong positive value to ourselves and our group, while attaching a negative value to certain other people and their groups. It is prudent to assume that we are all, to some extent, susceptible to egocentric and ethnocentric tendencies. The human species is one in which individuals and groups easily learn to blame others for whatever difficulties exist. But in the present predicament around nuclear conflict blaming is at best useless and most likely counterproductive.

A new level of commitment of the scientific community is urgently needed to reduce the risk of nuclear war. This requires a mobilization of the best possible intellectual, technical, and moral resources in a wide range of knowledge and perspectives. A science-based effort is essential to maximize analytical capability, objectivity, and respect for evidence—the outlook that is characteristic of the scientific community worldwide.

These efforts should bring together scientists, scholars, and practitioners in order to clarify the many facets of avoiding nuclear war. To generate new options for decreasing the risk, we need analytical work by people who know the weaponry and its military uses, people who know the Soviet Union, people who know international relations broadly, people who know the processes of policy formation and implementation, people who understand human behavior under stress, and people who understand negotiation and conflict resolution. Such analytical studies are likely to be more useful if they take into account policy-makers' perspectives, and policy-makers can benefit greatly from ready access to new ideas, a wider range of options, and deeper insights.

Commitment to Science Education

The rapid acceleration of technological and social change in recent decades sharply heightens the importance of our educational institutions. Indeed, during the past year we have experienced a sort of national rediscovery of education, particularly with reference to science and technology. We must address fundamental challenges in education.

1) How can we give all our children, regardless of social background, a good opportunity to participate in the modern technical world? In this time of high unemployment we must especially consider employment opportunity.

2) What constitutes a decent minimum of literacy in science and technology that should be part of everyone's educational heritage?

3) Given the rapidity of sociotechnical change, how can we make lifelong learning a reality so that people can adjust their knowledge and skills to new circumstances?

4) Since educational institutions will more than ever be trying to hit a moving

target as they prepare people for unpredictable circumstances, how can we prepare for change itself?

5) How can we enlarge that talent pool so that we can find promising people for science-based careers, regardless of their socioeconomic background?

6) How can we broaden the spectrum of the sciences so that modern education will become increasingly informative with respect to the human experience?

7) How can the educational system foster a scientific attitude that is useful in problem-solving throughout the society, in relating scientific principles to the major issues on which an informed citizenry must decide?

8) How can we achieve an informed worldwide perspective in an era of profound interdependence?

The American dilemma in science education involves a remarkable paradox. We have the largest and probably the most respected scientific community in the world, yet our precollegiate science education is at a low ebb. Is there a way to resolve this paradox creatively?

We must seek mechanisms to link the science-rich sectors of our society and the science-poor sectors—that is, connect the scientific talent of universities, colleges, corporate laboratories, and national laboratories with the elementary and secondary schools, thereby strengthening national capability for broad education in the sciences: physical, biological, and behavioral.

The linking of science-rich to science-poor sectors as partners is a means to both teacher education and curriculum development. We can learn from the successes and failures of the curriculum reform movement that followed Sputnik. Improvements in education can flow from the collaboration of classroom teachers with subject matter experts (for example, in physics, chemistry, or biology) and also with scholars in the field of human cognition and learning. Such collaborations could be an important step toward incorporating teachers of science into the scientific community. While major efforts must be made to improve the salaries of teachers, and especially those of science teachers, it is equally important to find ways to bolster respect for their profession and strengthen their morale. Participation in the scientific community would be helpful in this regard.

Closer links of elementary and secondary schools with colleges, universities, corporate laboratories, and government laboratories could include summer institutes for teachers, Saturday activities for teachers throughout the school year, summer jobs in science for teachers, and the preparation of curricular materials. Leadership from different sectors of society will be necessary for the major upgrading that is required. The schools are central to the effort, but they alone do not have the resources or the clout to do the job.

The Transformed World

The rapid, pervasive, and truly unprecedented transformation resulting from science and technology is a central fact of our lives. It calls for the strengthening of institutional capability for objective, scholarly analysis of critical issues based on a broad foundation of knowledge and experience.

Colleges and universities, academies, and free-standing institutes can mobilize a wide range of talent to address the great issues of our time in a sustained, fascinating, and effective way. They can give us a better chance to get the complex facts straight and to clarify the most promising options—all this in a way that is credible and even intelligible to nonspecialists. Such efforts can be helpful to open-minded policy-makers, but also—and perhaps more importantly in the long run—to the education of a broadly informed public on the great issues of our time and the policy choices available to us.

Surely the problems associated with the social and economic concomitants of technological change are not insuperable. The opportunities provided by the advancing technology, if judiciously utilized, suggest that it is worth a lot of trouble and hard work to find ways to make a decent social adjustment. We will require broad, multifaceted analytical work to understand more deeply what is going on and to anticipate insofar as possible the likely consequences of major technological trends.

To deal effectively with real-world policy problems requires novel conjunctions of knowledge and talent. Typically, many different facets of a complex issue must be taken into account. The great problems do not come in packages that fit the traditional disciplines or professions, however excellent they may be. Organizations such as universities, scientific academies, and research institutes can make a greater contribution than they have in the past if they can organize effectively to share information, ideas, and technical abilities widely across traditional barriers and systems. Of course, most advances in knowledge require specialization. Yet for crucial social purposes these pieces must somehow be related to each other.

A particularly valuable undertaking is the intelligible and credible synthesis of research related to important policy questions. What is the factual basis drawn from many sources that can provide the underpinning for constructive options in the future? This is especially significant in view of the fact that pertinent information is almost always widely scattered. Moreover, it is very difficult for the nonexpert and sometimes even for the expert to assess the credibility of assertions on emotionally charged issues. In the current process of world transformation, such studies are needed to tackle vital and complex issues in an analytical rather than a polemical way.

Whether it be toward avoiding nuclear war, strengthening education in the sciences, or fostering human resources in developing countries, there is a precious resource in the great scientific community of the United States—and its links to the worldwide scientific community—which can be brought to bear on these crucial problems. This involves activation of a wide range of the sciences and an unusual degree of cooperation among them. Furthermore, it involves linking analytical work with education in a variety of modes, for the general public must take an informed part in the decisions that affect all our futures. The scientific and scholarly community can deepen its contribution to pressing social concerns if it is informed and stimulated by those on the firing line, whether the latter be engaged in teaching poor children, struggling with policy dilemmas, or coping with international tensions. There can be a mutually beneficial interplay between social concerns and basic inquiry.

Conclusion

There is little in our history as a species to prepare us for this hypermodern world that we have so rapidly made. The transformation of the world will press us toward transformation of our institutions—to keep up with events, to understand below the surface, to look ahead and prepare, to enjoy the fascination of deep insights, to make wise use of technology, to relieve poverty and disease, above all to resolve the deadliest of conflicts. In the historic effort to avoid unmitigated disaster and fulfill the potential of our species, science can help profoundly and in novel ways. But to do so, the sciences must transcend their traditional boundaries and achieve an unprecedented level of mutual understanding, innovation, and cooperation. These efforts will have to go across disciplines, across sectors of societies, and across nations.

Let us hope that fundamental values of freedom, curiosity, opportunity, diversity, excellence, and human decency will guide our institutions as they evolve. These enduring values can make it possible for us to cope with the great problems of our time, to work steadily towards the humane uses of science and technology, and to take advantage of unprecedented opportunities that are emerging for the benefit of people everywhere.

Activation of Dormant Genes in Specialized Cells

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Summary. In several experimental systems the genomic capacity in specialized cells can be assessed by examining the activation of dormant genes. Since some of these specialized cells can be induced to change cell phenotype, all cell specializations do not necessarily involve irreversible genetic changes.

In the development of multicellular organisms, specialized functions of organ systems are achieved by their specialized cell types. When cell types once acquire the metabolic pathways for performing a special function, no further changes usually occur. We call this the stability of the differentiated state. It is now widely accepted that the process and stability of cell specialization are under genetic control. However, whether or not the establishment and maintenance of cell specialization generally involve irreversible genetic changes still has not been answered adequately. The support for and against genetic irreversibility has varied from time to time, opinion often being influenced by the organism studied and the techniques available. During the 1960's, the general view was that adult organisms retain the same set of genes as the nucleus of the fertilized egg, and that cell specialization is accomplished through the differential recruitment of genes and expression of their products. Gene losses in, for example, *Ascaris* and *Sciara* were considered special exceptions. Then with the explosion of highly sensitive molecular techniques capable of quantifying genes and determining nucleotide sequences in DNA, we became aware that in some cases genes can increase in number (gene amplification) and DNA can undergo rearrangements (*1*). However, it has not yet been shown that generally there are nucleotide losses affecting genomic totipotency.

In several experimental systems, the phenotype of specialized cells can be converted into a different phenotype. This conversion, when analyzed by molecular techniques, is shown to be accompanied by the synthesis of new and different gene products (RNA's, polypeptides, or proteins), an indication of the activation of dormant genes. Such systems provide a means for evaluating the degree to which cell specialization can be modulated and the degree to which gene function can be reversed. In this article we examine the current status of genomic capacity in specialized cells by analyzing the degree to which dormant genes can be activated in the experimental systems of cellular transdifferentiation, cell hybridization, nuclear transplantation in amphibians, and some cancers. In addition to discussing our data on nuclear transplantation, we point out that the fundamental phenomenon of induced gene activation is observed in these diverse experimental systems, as well as others. Collectively, these results demonstrate that a high degree of genomic information inherited from the zygote must be maintained during cell specialization because the stable phenotypes are reversible under appropriate experimental conditions.

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Cellular Metaplasia or Transdifferentiation

Specialized cells in vivo do not ordinarily change into another cell type. There are, however, a few exceptions to the stability rule among vertebrates where alteration in the specific characteristics of differentiated cells occurs. This phenomenon has been termed cellular metaplasia or transdifferentiation because it results in cell-type conversion. A well-known example of transdifferentiation is the Wolffian regeneration of lens from the pigment cells of the iris epithelium in several adult urodelen species. Almost a century ago, it was discovered that in the adult newt a new lens can form from the dorsal iris after partial or complete lentectomy (*2*). In vitro studies stongly support the widely held belief that iris epithelium cells (IEC's) are converted into lens cells after complete lentectomy of newt eyes. Dorsal iris epithelium, isolated and cultured in the presence of frog retinal complex, differentiated newt lens tissue that contained lens-fiber specific γ-crystallins and total lens protein (*3*). Even in primary culture, lens cells formed from IEC's derived from both dorsal and ventral irises and clones of IEC's have expressed the lens phenotype (*2, 4*).

Another example of cell-type conversion occurs during regeneration of the urodelen amphibian limb. Soon after the limb is amputated, epidermal cells migrate distally and cover the wound surface. The internal limb tissues (skeletal muscle, bone, cartilage, and other connective tissues) proximal to the site of amputation then dedifferentiate into un-