COMMENT: THE ROLE OF TECHNOLOGY IN SOCIETY AND THE NEED FOR HISTORICAL PERSPECTIVE

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The unique contribution the historian of technology and society can hope to make is to inject a chronological dimension. Hence historians are not likely to fit well among those who see technology either as an unalloyed blessing or as an unmitigated curse. Historians have, despite a lack of firm methodological assumptions, been piling up empirical evidence that technology has been a well-recognized factor in social change not only back to the Industrial Revolution but also back at least to Olduvai Gorge and the end of the Pleistocene glaciation. However, the most unlikely conclusion they could possibly draw from this chronological sequence is the one which Mesthene attributes to them—that technology as such is not worthy of special notice. Perhaps the econometricians have rubbed out the acceleration of productivity since the 1880s and have denied a change in time period between invention and adoption of technological components in recent decades. The historian is interested in precisely those social, cultural, psychological, and political effects which render the conclusions of the econometricians elegant exercises, beautiful in their way but divorced from the choices which men and women fixed in time have always had to make.

For the understanding of contemporary society, technology is worthy of such special notice that a program on technology and society cannot afford to overlook the possibility that important elements in the present interaction between technology and society took shape long before the 20th century. Even if one accepts Mesthene's proposition that the contemporary situation is qualitatively different from that of past societies, the way is still open to use the new insights our present technology and plight give us to reexamine the past with eyes better focused to understand the nature of technology in its interactions with society in any period. Two leading ideas of the present scene—the systems approach and ecological balance—have the possibility of combining to elucidate the nature of technology and innovation, but these ideas need a long time span to test themselves adequately.

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The framework of the history of technology as now practiced is the child of the Industrial Revolution and the patent system. The effect of the patent was to focus the history of technology on the individual inventor as the potential entrepreneur-innovator and also to focus on the individual mechanical device rather than the system as the unit of innovation. The structuring of the whole concept of technological change around discrete mechanical arrangements as the unit of innovation has persisted to the present and was almost unchallenged until recently. Since almost every systems innovation has certain crucial components without which it could not operate and certain components which were already available from the existing stock of technology, the patent-inventor-invention formulation has a certain utility. Thomas A. Edison was dealing with a systems problem in substituting electricity for gas lighting in the early 1880s, but he rightly focused on the invention of the high-resistance incandescent filament in a glass-enclosed vacuum as the component which was most dramatically necessary for the whole system to operate. Therefore he found it most persuasive and also most in tune with the patent system of reward and development to describe himself as the inventor of the discrete component. The history of technology has labored mightily to trace the history of some of the thousands of components and to unravel the thorny problems of priority and prestige involved in the title *inventor*. Yet even another generation of industrious work on such a program would still be unable to help Mesthene very much in unraveling the relation of technology to society in the late 20th century, the period of the greatest multiplicity of components.

Therefore let us ask the Harvard Program on Science and Technology to take its expertise in the modern arts back along the chronological axis of history sufficiently far to get a perspective on the systems approach applied to technology itself. Let us imagine the improbable—a historian possessed of both the systems approach and ecology. Let him try to define technology. He would take a look at Mesthene's definition, "the organization of knowledge for practical purposes," and, without changing it essentially, say that technology is man's codified ways of doing things to the environment. Such definitions abound in the literature, but they need translating into terms understandable in the late 20th century by technological man himself. The hypothetical qualified modern historian of technology (not myself, but one armed with anthropology, archaeology, and linguistics as well as systems analysis, ecology, and all the conventional scholarly appurtenances) might strip off all perplexities and complications to evolve a definition something like this: Technology is an information system which connects the species of biological organisms *Homo sapiens* with its environment. Skipping over the vexed problems of animal technology and the protohuman mix of tools and biological adaptation, the historian can find as far back as he can see a biological organism (a system in itself, about which we know something from present evidence) interacting with its environment, which includes both other organisms and the physical environment accessible from the surface of the planet Earth. Other organisms have reached a balance with their environment by biological adaptation, but culture, in addition to biological adaptation, has interposed itself between *Homo sapiens* and his environment.

Although one might conceivably see this ecological position of man in several ways—for instance, as an energy transfer system—the presence of language and society even at the earliest horizon makes the information system the closest analogue of technology. Not only does the human individual take in information through his senses, process it, and read out behavior which is adapted to the environment, but culture provides a kind of memory unit which processes information flowing in from the environment on a scale beyond any individual and stores it for future use. The conception can apply both when most of the feedback flows from the environment, forcing man to adapt, and when in more recent situations the quantity of feedback flows the other way, producing massive changes in the environment itself. Yet even on the earliest horizon the feedback flow is a closed loop and not necessarily overbalanced in favor of the environment. Men of earlier times could cut down the cedars of Lebanon with the efficiency of a bulldozer.

The information system which is technology could not get very far without language, since the naming of things made efficient information exchange with the environment possible. Yet language is not the only carrier of technological information. Tools themselves transmit messages to their users even as energy flows through them to the environment. Society is also a carrier, for fathers, mothers, and masters pass on to sons, daughters, and apprentices information which they cannot verbalize and which is embedded in the skilled and practical eye-hand coordination of the artisan. No wonder that until the 20th century the best way to move technological information laterally in space in a short time was to transport skilled artisans.

Only from the time of the Renaissance, and even then only peripherally, did a formal information carrier in the shape of a technological literature develop. Mining was an ancient art which had gone on for centuries before Georgius Agricola's *De re metallica* (1556) and showed every evidence of continuing without the aid of that masterpiece. Although formal mathematics, for instance, seems to put in a very late appearance among artisans, tools and the products of early technology speak eloquently of narrow limits of accuracy and coordination of complex relationships by men unversed in Euclid. Indeed, some evidence indicates a chronologically continuous grid of measurement underlying Western technology from the ancient world to the present.

Since each generation of man must solve certain systems problems or perish, the technological information is embedded in culture groups around certain fundamental adaptive mechanisms—food, clothing, shelter, mobility, protection. Reticulation of an industrial technology can mask these fundamental mechanisms, but no amount of affluence can eliminate their biological base. The historian of technology has here an organizing principle for analyzing the technological information which puts his many component histories into perspective. The origin of agriculture and the coming food needs of the exploding population are all one subject because every generation must have the technological information to provide itself with food. McCormick's reaper and the horse collar of the Dark Ages have had center stage in the history of technology, but the magnificent unity of the history of corn, *Zea Mays*, in its full social setting with man, is much more in tune with an approach to technology which makes food provision a system equally present in every society.

Out of the necessity to preserve the fundamental technological systems to support life comes the immense stability (hopefully a better word than conservatism) of technological tradition. Especially if the surplus wealth of the community is low, an experimental attitude is disastrous. Furthermore, the redesign of components can only take place within the confines of a system that must maintain its adaptation with the environment. Therefore, innovation merits the suspicion of a peasant whose culture has taught him through the hard experience of his ancestors the course most likely to ensure his harvest.

Technological change is not, however, a new phenomenon. Although the system hunts for stability and, if the feedback from the environment remains steady, will tend toward a diminishing oscillation in technique as the tradition becomes set, the input from the environment is never completely free from change. Geology has seen to that, for the end of the glacial epoch forced massive technological change and systems innovation on *Homo sapiens*, making him into the innovating animal. When his ecological niche changes, the feedback into his culture computer tells him something is out of balance, and he responds not only with change but also with a search for a new equilibrium adapted to the changed condition. In this way the stability of culture and the pressure for change brought about by a fluctuation in the environment (including the changes induced by the impinging human population itself) form a tension out of which comes adaptation. Most animals have to stay with one ecological niche or become extinct or evolve new biological capability, but *Homo sapiens* developed the ability to change niches through technological adaptation long before the conventional dawn of history. No doubt the process of change often occurred over many lifetimes, and tradition could change without breaking the continuity of parent-to-child transmission in time. Yet not all technological change in earlier times was necessarily multigenerationally slow. A plow could spread far across Europe in a few years, and the cliff houses of Mesa Verde lost their inhabitants within the memory of a single generation.

Science has received so much praise and blame as the prime source of technological change in the present era that the Harvard Program on Technology and Society cannot avoid considering science as a part of its field of investigation. Mesthene almost never mentions science, to the extent of making American accomplishments in national defense and space exploration "technological successes." Yet his present era is precisely the time when, if ever, science has intruded itself onto the technological scene. Hence, the historian might carry his hypothetical analysis one step further and ask if science will yield to the viewpoint of systems analysis and ecology.

Despite many careless modern statements of the separateness of science and technology up to the late 19th century and their intimacy thereafter, the analysis at first glance makes the two appear surprisingly similar. Science, like technology, is an information system embedded in culture. It too mediates between man and his environment. It too is a social process concerned with a memory bank which stores information and passes it from one individual to another, including those in the younger generation who will take their places in an unbroken chain. It too relies heavily on language. It too has embedded in its tradition a mathematics tied to a measuring system.

Finally, science also has tools to supplement man's senses, which are in themselves carriers of information beyond the verbal and mathematical content of their readouts. Nothing has confused the historians of science and technology more than the fact that science floats on a bed of technology. As an information system it has hardware. Not only is science dependent on technology for the instruments specially made to its order. It rides along on the artifacts of general technology, as when the building of the transcontinental railroad enabled biologists to reexplore the trans-Mississippi West with great efficiency and systematic results. That example perhaps makes the same point more clearly than saying that science rides along on a rocket to explore space. The rocket is technology, but the exploration is science.

The recognition of science and technology as kindred information systems should not, however, deter the historian from seeking among the similarities for the differences which have led these two systems to maintain separate identities and at times almost to lose touch with each other. On the other hand, as at present, the two have become so intertwined that to recognize the boundary between them is the hard problem.

The first difference between science and technology that becomes apparent is a radically different emphasis on the various carriers of information within the systems. While the technological instrumentation carries a freight of information and while the organizations of science work, to an extent, on the master-apprentice pattern dominant in technology, the predominant carrier of scientific information is the corpus of formal literature. The linguistic channel and mathematical channel in the formal literature define the scope of science in any given age. Hence the long detour from the Greeks via Alexandria and the Arabs to Western Europe in the 13th century is mainly a matter of written texts.

The second difference, somehow linked with the first one, is that science is not a closed-loop feedback system. It has inputs from the environment, but it channels them into the memory bank—the formal literature—without the expectation on the part of a society that adaptive behavior must be immediately forthcoming. The process of abstraction, which the scientific information system began to accomplish in ancient times, broke the loop and relieved the system of the necessity of producing an unbroken series of adapted systems in all periods to provide an ecological niche for the species. The time span available for the processing of information within the system is greatly increased, and the number of optional solutions also greatly increased. In place of culture as a whole being the path for the information system in a reciprocating loop as in the case of technology, the scientific information system developed its own more limited and more disciplined cultural milieu in the scientific community. Solutions are stored for varying periods of time in the formal literature and then retrieved by the instructions of the scientific community when certain standards of cogency are met. Here is not the place to discuss the complicated rules of priority, verification by experiment, and achievement of consensus by which the scientific community processes information.

Suffice it to say that despite the similarities of the two systems, they had diverged significantly during the Middle Ages. When they began to interact toward the end of that time, the scientific information system received a large input from technology, and indeed the scientists without the help of the artisans of the Renaissance would have remained seriously hampered by a deficient experimental and observational capability.

By the late 19th century the two systems had again diverged significantly, and now it was the scientific information, with the dense matrix of options it had developed over three centuries, which made science a major input into technology. That they are both information systems with a common linguistic and mathematical tradition made their mating easier. At first science appeared as the bestower of components on already functioning technological systems. The atomic bomb might be viewed as the culmination of component bestowal from science to technology. In the post-World War II period, although the flow of science-oriented components has by no means ceased, the possibility that science might develop optimal systems to substitute for whole technological systems has become a reality. The gain in this situation is the number of matched components that become available rapidly and also the possibility that direct control of man-environment adaptation can be achieved on a systems basis rather than left to the closed-loop cultural interactions of technology.

The danger in the situation lies in two directions. In the first place, even the most science-based technologies are still made up to a large extent of traditional technological components, some of which have remained unchanged for centuries and are highly adapted, especially to man. They may be superior to a scorched-earth innovation in the name of progress. And, new or old, the system must continue to be respectful of the biological organism that *Homo sapiens* remains. The substitution of jet aircraft has not rendered walking obsolete. In the second place, the dynamics of the man-environment adaptation is so poorly understood that the trade-offs of gains and losses in hasty and partial innovation of science-based systems may after the fact produce social and ecological disaster.

If the Harvard Program on Technology and Society could use a modern approach to the history of technology, it might be able to go a little way toward sorting out the mix of systems—some science based and some a direct heritage of man's earliest experience—which make up the totality of 20th-century technology. It might also be able to avoid the extremes of unlimited optimism and bitter pessimism by an analysis of the middle ground of cost and benefit. An understanding of many different rates of change and the relations between them and a quest for balance in the man-environment ecological system might provide a standard of value which would restore to proud and anxious modern man a measure of both courage and repose.