Intelligence, Information, and Education

Various systems—brains, computers, and institutions—are developed to handle new information in new ways.

R. W. Gerard

Man is in danger because his control of power has increased so much more rapidly than have the coordinating mechanisms for handling it. . . . If man is to utilize successfully the new resources at his disposal, to enhance his civilization rather than destroy it, he must apply the scientific attitude and method to human affairs to a degree hitherto undreamed of; the engines of civilization cannot be run by emotion and guess but require reason and foresight. We scientists and teachers, makers of the minds of men, have an especial obligation to foster this attitude. We must press, with our colleagues in other fields of knowledge, for every possible support and encouragement to create new social inventions, new and more efficient coordinating mechanisms in the epiorganism (or social organism).

In the mid-1940's, when I wrote the above (*1*), computers were inconspicuously starting into existence, operations research was a small war baby, systems engineering and behavioral science had no public identification. Today, electronics, miniaturization, magnetic-optic recording, and solid state physics in general, on the one hand, and the mathematics of relationship—set theory, game theory, information theory, topology, and taxonomy—and that of quantification, have together given us the material and intellectual tools for tackling these larger problems. Computer systems—automata—are making possible the high-speed and complex manipulations of symbols and of information in general which are essential for dealing with the large and complex systems man has created. But before we examine this area further, I ask your attention to the broader perspective in which it fits.

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Entities

The universe, to the naive observer, is indeed "a blooming buzzing confusion"; and man, as individual child in his narrow perceptual world or as culture-laden savant in his wider conceptual one, proceeds to structure it. Entities are dissected from their surround; indeed, the mechanisms of sense organ and nervous system are such as to emphasize the margins of material objects and also, now being examined, those of acting and feeling and conceiving, as well as of perceiving. Material objects, commensurate with man's own space and time dimensions, were the first entities recognized and became the first nouns of language. Later, these structural units or entities were further subdivided into smaller and smaller components, a morphological dissection, and were also grouped into larger and larger collections, the taxonomic or systematics approach. Later, also, functional and then developmental units received attention—forces as well as substance, reaction times as well as products, the nerve impulse as well as the nerve fiber, the role as well as the individual—and the universe began to emerge as a hierarchically organized set of systems, from subnucleons to supergalaxies, with man's special interest in living ecosystems and human social systems, each system having its structure or "being," function or "behaving," and irreversible development or "becoming."

The great forward thrusts of intellectual ordering and of practical manipulation have come from the creative rethinking of the basic entities to which we give our attention. In science we commonly think that quantitative precision is our great strength; and, certainly, it does give science its essentially unique power of precise prediction and hence control. But before measurements can be meaningful they must be directed to the right things and, even in science, finding these things is the major achievement; entitation is more important than quantitation. Recall the comment to a student who was ignorant of the number of birds in a flock or of bees in a swarm but certain that there were seven dwarfs with Snow White: "So you know more about fairies than you do about birds and bees?"

Many of the powerful and still satisfactory entities of physical science were established three or four centuries ago, along with a few of those of life science. In social science, it might be questioned whether a Galileo or a Harvey or a Lavoisier or a Darwin has yet appeared. Nor is this surprising, since social science deals with the most involuted and complex systems of which we know. Happily, what is strange and difficult to the formed adult is often comfortable to the forming child.

Interaction

Any entity or system is continually interacting with its environment. In the biological realm, organisms were primitively, in relation to the environment, sinks into which matter and energy flowed. As more active and complex organisms evolved, this relation gradually changed from that of sink to that of source; and man, particularly, has pushed around his environment prodigiously. This active role has become possible by the development of structures and processes that enable organisms to deal with quality more than quantity, to discriminate and react to particular patterns, and to trigger off large amounts of directed energy and so produce a response more powerful than, but highly appropriate to, the original stimulus. The attendant shift in emphasis was from energy and matter to information.

Man, collective man, has faced and largely solved the physical and biological problems of existence. He has captured ever more energy, from fire to nuclear piles; he has found or made ever better materials, from bronze and fibers and glass to tailored polymers and alloys; and he has controlled living organisms to give an ever safer

existence, with mostly stable and adequate food supplies, the absence of predators, and rapidly increasing mastery of infectious and other diseases. Man has, in fact, largely cut himself off from the external environment and created a hothouse internal environment of culture in which he lives in remarkable physical comfort. Psychosocial comfort, even safety, is another thing. Lowered death rates, faster transport, and universal communication have produced more men having more interactions on more topics; and man's primary concerns today are with other men and with the communications that flow between them. Our lives are spent overwhelmingly at the symbolic level, and we live in a man-made sea of meanings. And the sea is still rising more or less exponentially.

Evolution

Evolution is the long-range molding of a system by its environment and, clearly, the more malleable the system, the more readily it will change. This is a sort of learning by experience and applies equally to the evolution of the species, the development of the individual, the history of the society, and, in the more specific sense, to the education of or learning by the individual. But the crowning achievement of evolution is not learning but learning to learn; not being malleable, but increasing malleability. The great inventions of living things contributed to such an improved fixation of experiences—the array of perpetuating but mutable genes; the shuffling of the gene array by sexual reproduction; the functional specialization of multicellularity and the appearance of an impressionable nervous system; the advance in quality, connections, and number of the neural units until such nuances of pattern could be recognized and communicated that social groups could arise; finally the successive development, in a collective culture, of symbols to represent things, perhaps hundreds of thousands of years ago; of organized symbols or language, perhaps tens of thousands of years ago; of organized and tested symbols, or science, in recent centuries; and, upon us in only decades, computer systems or automata, prostheses which will extend the brain's ability to manipulate symbols just as the bulldozer is a prosthesis for muscles and the microscope, telescope, spectroscope, and laser are for the eye.

As symbol manipulation and information processing have become easier —from ideogram to alphabet, from cuneiform or Roman counting to Arabic decimals, from papyrus and pigments to paper and printing and on to magnetic disc or thermoplastic storage—so also greater possibilities, then requirements, and then demands for improved use of information in exploiting the universe have developed. Man as a whole, and not only in the underdeveloped areas, is continuously experiencing revolutions in expectations and in performance. The argonaut on earth or the astronaut in space steers ever further; the architects of matter and ideas and relationships, artists and scholars and social entrepreneurs, build a richer living space; and all men must adjust themselves to the new challenge of the new bounty.

As science and technology have shrunk our world and expanded our universe, so they are creating the intellectual and material tools for dealing with the more complex systems they have generated. Automation has been on the rise since the hand ax supplemented the hand and the canoe relieved the foot. Horses and then horsepower aided and then largely replaced muscle, and man suffered in, but emerged with true gains from, the machine revolution. Now the white-collar occupations are feeling the advance of automation and, as computer systems develop, the encroachment, from one viewpoint, or the aid, from another, will rapidly permeate further. Whether boon or burden (and I remain deeply convinced that it is the former) the taking over of lesser tasks by automata clearly does demand that humans be able to handle the greater ones. And this implies the upgrading of human capacity on a large scale. Indeed, as Gunnar Myrdal urges (*2*), a business upsurge in this country would today bounce back from the low ceiling of managerial talent.

Learning

Men can be upgraded. At the strictly biological level, there is no question that the principles of genetics and selection, used widely by man in the plant and animal world, could be used to enhance desired traits in man. The problems involved now are more those of goals and of ethics than of means. But, while the manipulation of racial development is not imminent, the manipulation of individual development is upon us. Here, the basic knowledge is more fragmentary and the means less clear, but the manipulation or control of behavior is also clearly possible. Oddly, this notion is strongly abhorrent to most of us when presented in the abstract, while we spend much of our lives specifically trying to influence the behavior of others. "Manipulation" seems to carry the unpleasant connotation of manipulation for selfish purposes and to the detriment of the person manipulated; yet a moment's thought shows that most manipulation is at least intended to benefit its recipient—the importance of parents guiding their children, teachers educating their pupils, doctors advising their patients, and ministers leading their parishioners is surely greater in volume and impact than that of the salesmen and advertisers and politicians prevailing upon their audiences—and even in the latter groups, unselfish ends are far from absent. In any event, man does manipulate man, and with increasing knowledge and skill; which brings us back at last to education.

As a lifelong student of the brain and of behavior I am keenly aware of the great capacity of the brain to learn and to learn to learn, and of the rather rapid decrease in these high potencies from infancy onward. Baby chimpanzees (or humans) denied the experience of patterned vision during the early months of life may never achieve the effective discrimination of patterns; motor skills are greatest when acquired earliest; it is almost impossible for an adult to master a new language without showing an accent. Rats given rich experiences during growth show a thicker brain cortex than those deprived of such experience. In general, functioning increases the ability to function, in the intellectual realm as in the physical one; exercising the brain is as productive as exercising the muscles and the cardiovascular system.

There is, happily, a ferment throughout the educational system, with a shift from forced feeding of facts to improving mental digestion of them. The exciting outcomes of preschool language teaching, of introducing "ad-

vanced" mathematical concepts in the lower elementary grades, of bringing the theories and experiments of physics and biology almost at one step from the graduate school to the high school—and of finding the recipient enjoying his experience and eager for more—offer dramatic evidence of what can be done. The brain responds to challenge; intellectual as well as physical performance can be made to improve, and world's records will be broken in both areas.

Instruction

Education is the most extensive continued activity of man. The large demands for funds and personnel cannot ever be fully met, and top-level teachers and facilities are of necessity the exception, not the rule. Perhaps because of the great pressures and the small external rewards, education remains one of the less advanced sectors of behavioral science. The schools and universities of today still follow the lines made possible by the invention of printing, books, and libraries, supplemented in a few areas by experience, often pretty passive, in laboratory or studio or field. These technologies are no longer adequate to meet the surging qualitative demands that are now superimposed on the quantitative ones.

Teachers are learning aids, and the best ones will presumably never be matched by any other kind of learning aid. But both need and opportunity dictate that other learning aids be developed and utilized for as much of the educational process as they can be upgraded to handle. The more routine aspects of teaching and learning can already be handled by technology—drill in spelling and vocabulary, reckoning, and hearing and speaking a foreign language (and recording the student's progress in his studies) can even now be carried on very satisfactorily by picture typewriters, by "teaching machines," by audio tapes and language laboratories.

With the growing paraphernalia of audiovisual resources, from slides to video tapes of great actors, dynamic teachers, incisive experiments, or distant adventures, almost any kind of information or experience can be brought to a student almost anywhere and at his own individual tempo. With computer systems able to marshall cartridges of tape or microfilmed texts, to store billions of bits of information in their own internal and external memories, with individual and random access at times ranging downward from a few hundredths to a few billionths of a second; with logical and numerical processing of many different information trains in the same computer unit, either interleaved or in parallel and at great speeds, so that hundreds or thousands of terminal consoles can be serviced with no observed delay by the user; with terminals and programs that allow a practically conversational personalized dialogue between each student and the machine in typed symbols, light pen drawings, and television tube displays, and, soon, by actual voice communication; with all these, such an information system can become a veritable tutor for the individual student.

It may well be that the school of the future will carry on its intellectual functions (and it is obvious that the present school serves many additional functions, such as motivation and inspiration, which will continue to require attention) largely through consoles placed in individual homes, with the aid of which each student can go through appropriate lessons, tailored to his own psychological profile and past performance experience, progressively built into the computer's picture of him; can enter into single or group discussions with other students and instructors via the connected television tube and circuitry; and can have his entire learning course and achievement automatically recorded and rewarded by the same system. I repeat, life and education have other values than those of the intellect; some, but not all, of these can perhaps also be dealt with without a teacher in the round —as they are by Olivier's Shakespeare on the screen. There is no need to dehumanize education while updating it. The technology for all this is now upon us, but many are discouraged by the great effort needed to create the "software," to bring information into a form usable by a computer and, in general, to go through the difficult developmental stages. I can only suggest that it has taken millennia to build our culture and to store it in books and in brains. To first transfer it to computer systems and then learn how to manipulate it effectively by them will require two magnitudes less of time and yield two magnitudes more of usefulness. Such instruments, moreover, will make possible the rapid development of a science of education, since experiments can be noted and followed and the results analyzed as was never before possible. Here, as in other aspects of behavioral science, from simple data processing through model testing, to actual large system simulation with men and machine interacting, computer systems at last are making available the needed technology.

What has been said about educational methods and science is applicable one way or another from prekindergarten through postgraduate training. When we consider the content to be taught and the organization for teaching, differences in the different levels become more important. The primary goal of lower education is to enculturate the new arrival into the community, to make him comfortable in the internal environment of his group; the primary duty of higher education, excluding the further introduction to advanced and specialized areas of the culture, is to teach its recipient to question the culture in which he finds himself. The youngster of a couple of centuries ago and of today needed the three R's to simply get on in his social world. Earlier, such skills were quite unnecessary and almost nonexistent; in the future, it is quite conceivable that quite different techniques of symbol handling and communication will become the basic skills. Even in the graduate school, I understand that a few universities are now accepting mastery of a computer language as an equivalent to mastery of a contemporary foreign tongue.

The University

I would like to describe the exciting plans we are developing at U.C.I., the new University of California campus at Irvine (the emphasis on computer systems and a joint program with I.B.M. has gained us the friendly nickname U.C.I.B.M.), but must be content with a few sentences. A university is a system that creates, stores, processes, and communicates information. A computer system stores, processes, and communicates information (in an on-line rather than batch fashion, as with books); and, in the sense that mathematics, though a great tautology, creates information, so does a com-

puter. A wedding of these systems will be explosive. A central processor will one day be able to call on any kind of stored information at the command of the individual user operating a terminal in parallel with but independent of hundreds of other terminals. Tapes and discs and data cells, microforms, and audio and video films in cartridges, can store data (on students, faculty, operations, fiscal matters), information from books, and findings of research; and can store programs for presenting these, as appropriate, to administrators, scholars, investigators, and students. A student, for example, soon will be able to sit in a study carrel, laboratory, or dormitory at a console, with typewriter and audio and visual devices permitting input and output; will sign in for a particular lesson; and will be privately tutored by the computer—painfully (50 hours of work for 1 of output) programmed by teachers to handle all but the more idiosyncratic situations—which carries on with him a dialogue in real time and brings information, gives guidance, or demands his ongoing responses as performance indicates. Local interaction with other students and teachers, even if they are not physically together, is also possible by video. Later, by decades, such communication will extend over great networks, and universities will be vastly different institutions—if they retain a separate entity!

To return to the here and now, from the possibilities of systems science and its allies in obaining the best of both possible worlds, there is not time to press into the problems of higher education, with the many running battles between liberal and professional demands, of depth versus breadth, of the specialist's expertise versus the generalist's understanding. Whatever the particulars, however, I would, in closing, urge any institution examining its future to seek an organization and a curriculum that will: (i) challenge rather than placate the young; (ii) foster the intellectual as well as the intelligent; and (iii) favor fluidity and change.

The first point has been discussed earlier; the following analysis by Richard Hofstadter (*3*) will sufficiently exhibit the second one:

> Intelligence is an excellence of mind that is employed within a fairly narrow, immediate, and predictable range; it is a manipulative, adjustive, unfailingly practical quality—one of the most eminent and endearing of the animal virtues. Intelligence works within the framework of limited but clearly stated goals, and may be quick to shear away questions of thought that do not seem to help in reaching them. Finally, it is of such universal use that it can daily be seen at work and admired alike by simple and complex minds.
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> Intellect, on the other hand, is a critical, creative, and contemplative side of mind. Whereas intelligence seeks to grasp, manipulate, re-order, adjust; intellect examines, ponders, wonders, theorizes, criticizes, imagines. Intelligence will seize the immediate meaning in a situation and evaluate it. Intellect evaluates evaluations, and looks for the meanings of situations as a whole. Intelligence can be praised as a quality in animals; intellect, being a unique manifestation of human dignity, is both praised and assailed as a quality in man.
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> A good deal of what might be called the journeyman's work of our culture—the work of lawyers, editors, engineers, doctors, indeed of some writers and of most professors—though vitally dependent upon ideas, is not distinctively intellectual. A man in any of the learned or quasi-learned professions must have command of a substantial store of frozen ideas to do his work; he must, if he does it well, use them intelligently; but in his professional capacity he uses them mainly as instruments. The heart of the matter . . . is that the professional man lives *off* ideas, not *for* them. His professional role, his professional skills, do not make him an intellectual. He is a mental worker, a technician. He may *happen* to be an intellectual as well, but if he is, it is because he brings to his profession a distinctive feeling about ideas which is not required by his job. As a professional, he has acquired a stock of mental skills that are for sale. The skills are highly developed, but we do not think of him as being an intellectual if certain qualities are missing from his work—disinterested intelligence, generalizing power, free speculation, fresh observation, creative novelty, radical criticism.

To build flexibility and change into any institution, my third point, is a major problem, and one aches with understanding of the wry comment of a university dean, "It is as difficult to get the faculty to change the curriculum as it is to move a graveyard." One certain way of promoting flexibility is to avoid crystallization, even at the expense of confusion. This was Franklin Roosevelt's skillful technique, as pointed out by Richard Neustadt (*4*); and I have an organizational scheme whereby the individual professor functions in his research capacity with one group of colleagues and through one administrative channel and in his teaching capacity with other colleagues and through another channel; but younger and wiser heads have been more impressed by the confusion than by the flexibility and I shall not detail it here. (A related plan is, however, in successful operation at a large university.)

Science, in its broadest sense, is about to make great contributions to education itself; indeed, there will soon be a true science and technology to supplement the art in this field. More students will be carried on to the higher reaches, and capacities for learning will be exercised early and utilized longer. Institutions of learning are about to undergo profound modifications, and new material will be taught in new ways, hopefully with richer outcomes. Social evolution continues, man is still learning to learn, and the demands on an educated citizenry spiral up. Indeed, we must gird to the future, aided by the resources of modern technology. Perhaps some day we shall even come closer to taking the splendid advice of Fouchet, "Carry from the altar of the past the fire, not the ashes."

References

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4. R. E. Neustadt, *Presidential Power* (Wiley, New York, 1960).