FOR THE RECORD

Marking the Second Frontier

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Educators have long been responsive to short-lived fads. For a few years this or that seems to hold the key to solving whatever is problematic in education. Thus programmed instruction, competency-based training, back-to-basics, and numerous other causes have caught the imaginations of educators for several years, only to recede into obscurity. Interest in computers and education had such faddish qualities a few years ago, as the microcomputer caught the imagination of many parents, educators, and children. Computing was hailed as the new frontier in education. About 1984, that faddish interest distinctly weakened as people realized that computers in education were no quick fix to educational needs.

One then began to hear the question put with increasing frequency: Would computers in education be another in the series of technological disappointments suffered by educators? Film, radio, television, have all been heralded as revolutionary reforming forces in the realm of education. Despite the ballyhoo, however, they have amounted to developments far less influential than their heralds had predicted. Radio in education is almost a nonexistent influence, and, somewhat more happily, at least, film and television have become useful supplements to established practices, but not anything transformative. Currently computers seem destined to a similar status, patient drill-masters that occasionally supplement didactic explanations with a memorable simulation.

Before acquiescing to this appearance, however, let us reflect on the multiplicity of time scales that are relevant to the flow of human experience. The first interest in computers in education arose with the early excitement over the microcomputer, which took hold as a novelty. That new-frontier status was perforce short-lived, lasting about five years—from 1979 to 1984. The novelty of a technology differs fundamentally from its productive duration, however, and we need to find the time scale appropriate for measuring the probable duration of computers as a developing educational influence. This will not be short.

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Geologic time unfolds in movements relative to which our lives are mere instants. In contrast, journalistic time consists of units that endure a day or week. The time scale of fashion consists of seasons and years. Politics seems to unfold to rhythms that are slightly longer, say six months to several years, marking the ascendancy of one or another administration. Economics changes at a pace measured in still longer units, very roughly from one year to a decade or more, several if one attends to the longer periodicities of the business cycle. What sort of time scale is appropriate for charting educational change and the role of new technologies in it? It is not the interval according to which pedagogical fads follow one another.

In thinking about the time scale appropriate for marking educational change, one must note when the major pedagogical changes that still condition educational activity began. The current structure of higher education derives largely from the late nineteenth century, when the elective system of undergraduate work and the spectrum of professional schooling were introduced widely. These curricular concerns still seem to be live issues, ones over which people work and disagree, ones capable of yet further development. For instance, a wise translator, Alan Bloom, has now become a best-selling writer by sharply attacking the relativism inherent in this century-old educational structure. Neither Bloom nor anyone else, however, seems to be able to conceive a workable alternative structure to this broad, latitudinarian curriculum of higher education, an alternative that will institutionalize a more ethically rigorous, aesthetically discriminating cultural apprenticeship. Continued criticism of a long-enduring status quo simply indicates that the real period of educational change in this area is well over a century in duration. Compulsory schooling at state expense is also a nineteenth-century idea, on the implementation of which we are still at work, with the prevention of dropouts being an issue of national concern. The twentieth-century idea—lifelong learning or *l'éducation permanent*—is still largely just an idea, with the conditions requisite for its implementation only beginning to emerge in the more advanced communities around the world. Here the appropriate period of educational change would seem not much shorter than the century.

With respect to technical systems, a similar slow, historic pace can be charted. The technological change that is here of interest is not the pace by which design improvements within a given technology may be introduced. These flow into practice every year or so, according to the complexity of the product and the potential profitability of its incremental improvement. The change of interest here concerns the introduction and development to maturity of a major technical system itself. Phone systems, introduced in the late nineteenth century, are still significantly evolving. The Eiffel Tower, representing new architectural technologies of iron and steel structures, elevators, sheath walls of glass and other materials, and the like, will soon be one hundred years old, with the architectural types that it symbolizes still showing great room for further development. Automobile transportation is a technical system introduced nearly a century ago, and it can be expected to continue evolving for many years to come with major improvements to the safety and economy of the complete system still feasible. Air transport is well over eighty years old; radio is nearly the same; television has existed for over half a century. All still have vast room for further technical development. Such facts about common technologies suggest that technical systems of substantial complexity require one to two hundred years for the development of their full potentialities, perhaps even longer.

As a technical system, computing, like television, is about fifty years old. Most observers would hold, however, that television is a more mature technology, one that has more fully disclosed its potentialities, compared with computing. The reason for this relative maturity is quite simple: The technology of which television is an instance is in fact considerably older than computing. Television is a major subsystem within analog electronic broadcast technologies, which are about eighty years old, whereas "computers" stand for digital electronic systems, a more fundamental, newer technological system, capable of a much broader range of implementation. Analog technologies use changes in one medium, say electromagnetic waves, to represent changes in another medium, say sound waves or changes of illumination along a path back and forth, filling a phosphorescent screen. The system is inexpensive and efficient, but inherently prone to error, which we experience as noise, static, interference.

Digital technologies do not transmit one thing that is analogous to another, the real matter in question. Rather, a digital technology transmits exact, or nearly exact, values, as precisely as these can be represented in binary code. If the real matter in question comprises a set of discrete components, say the letters and words of a text, the members of the set are transmitted as such in binary form. If the real matter in question is, in contrast, a continuous-wave phenomenon, a representation of the wave is created, consisting of numerous samplings of its values at discrete intervals, and the values of these samplings are transmitted in a way that is inherently resistant to error, for the code is direct and simple and subject to error detecting and correction. The key to digital technology, compared with analog, is the digital absence of ambiguity: It deals with successive states, either-or conditions in which a circuit is either off or it is on. In contrast, the analog technology deals endlessly with the torturing indefinite in which each successive state differs from its predecessor by a nearly infinitesimal increment. The analog approximates one whole with another; the digital samples the whole and reconstructs it from that sampling.

In this sense, digital technology is a radical innovation. Insofar as something can be described accurately in binary code, it can be *recreated* from that code. The matter is not merely approximated or represented, but fundamentally subject to recreation, a second instance of the thing, not a mere copy. This condition is one of the technological sources of the more recalcitrant human problems of spreading computing technologies. For instance, copyright laws seem to break down in digital environments because the familiar dynamics of reproduction do not seem to hold. Copies, in the familiar analog realm, are costly to make and at best approximate, leaving clear traces of what is the original and what is the copy. In the digital realm, copies are nearly costless, they are often indistinguishable from the original, assuming some real meaning to "original" can in fact be attached to something substantial. In short, digital computers using binary code to describe and act on all manner of things are a profoundly new technology, one that will probably have, relative to other modern technologies, a very, very long period of development. Thus the significance of computing and its educational influence should be measured along a duration of at least one or two centuries, if not considerably more, and of that duration, only fifty years have passed.

Recognizing now that the educational significance of computing should be measured on a long time scale, we are still left with the question of what that significance is. Computers are artifacts, designed and manufactured tools, whereas education is a preeminently cultural phenomenon, something that takes place through and for people. The history of education is not coextensive with the history of educational tools and stratagems. Will the cultural consequences of computers be contained *within* the culture, facilitating familiar activities within it without overtly changing human repertories of thought and action? Or will those artifacts have a substantial influence *on* the culture, empowering people to act and think in ways in which they could not have formerly acted or thought? To come to grips with this question we need to reflect, not on the technological evolution of computing, the first frontier, but on the evolution of its cultural influence, the second frontier.

Unfortunately, discussions of technology and culture often proceed with an ill-defined set of conceptual distinctions. In particular, commentators chronically render questions of determinism simplistic because they address the phenomena with inadequate concepts. In what follows, I shall suggest that we are in the midst of historically irreversible change, and with that some readers will be inclined to dismiss the suggestion as an example of technological determinism. It is not. Numerous phenomena are voluntary and nondeterministic, but irreversible once commenced. When irreversible actions have been initiated, they must be allowed to carry through to their conclusion, perhaps with some adjustment concerning the duration of the process and the pattern of attention associated with it, but without much voluntary control over the unfolding process. Swallowing is a good example. To swallow or not to swallow is a voluntary behavior. But having started to swallow something, I cannot casually decide midway through the action to unswallow it, or even to stop the swallow except with the risk of results that will certainly be undignified if not dire. History writing would be much more illuminating than it often is if more attention were paid to understanding the dynamics of irreversible actions without the premature brickbats of deterministic explanations being bandied forth.

Irreversible actions are actions the initiation of which is entirely contingent, but that once initiated follow an inherent course that has a set direction in time. Will it as you may, you do not grow younger. The boy at the edge of a stream may ponder for many minutes whether to leap or not, but once he coils and leaps, he cannot unleap, but must let the action carry through to a splash or a dry landing, whichever his strength, judgment, and the actualities decree. Most action is irreversible in this sense. I hope that my house will not catch fire, but should it catch fire and start to burn, I cannot reverse that phenomenon; I can at best put the fire out and repair the damage. Yes, we do try to intervene in irreversible phenomena and force them to follow a more desirable course than they would follow without the intervention. Note, however, the conceptual structure of such intervention: We recognize a normal course for the phenomenon—the materials of the house and the laws of combustion. Then we try to devise strategies for altering the normal course by adding further causalities to those irreversibly at work.

In its broadest sense, a *frontier* is what is crossed when an irreversible action has been initiated. The discovery and opening of a new frontier in a geographical sense is a typical irreversible phenomenon. The discovery was contingent, but having made the discovery, a people can do little but explore the discovered domain because they simply cannot undiscover it. Computing in education has a second frontier because an irreversible phenomenon of historic significance has been initiated that will deeply affect the potentialities and constraints of education. We can explore what lies beyond this frontier; we cannot return to a world in which the frontier does not exist.

Thus, our premise here is that we have initiated an irreversible action in cultural history in commencing to use computers for diverse activities in our culture. I think we can describe relatively precisely the nature of that irreversible action. To state it directly, the irreversible cultural action that we have initiated has two related components. The first consists in substituting a new form of coding—binary code—as the basis for storing and retrieving all the contents of our culture. The second consists in adding to the ancient cultural discovery of how to externalize memory outside the human mind, a very modern, portentous ability to externalize intelligence also outside the human mind. These two components are consequences of the introduction of digital technology, as noted above. What can be described in binary code becomes subject to recreation in multiple instances. People have initiated the description of all prior cultural achievements in binary code as well as the specification of diverse capacities for intelligent action in binary code. This second frontier is not simply technical, but deeply cultural. We have crossed it irreversibly. Discovering the possibilities beyond it will be a long, exciting journey.

Culture, as it has accumulated in history, is a vast store of externalized memory, memories that are put into things outside of human brains, into things that endure, inert but stable. Books and buildings, pictures and songs—all are memory externalized. Education has consisted largely in learning how to nurture and use a workable selection from this vast store. Up to now, to record things in externalized memory, a wide variety of coding mechanisms have been used—each medium of communication really has represented a different system for coding information outside of the inner memory of the human mind. The codes of writing are different from those of pictorial representation, which differ in turn from those of sculpture, architecture, still photography, or film. Culture has thus been divided into many domains of storage and retrieval, by the multiplicity of coding systems requisite for preserving it in external memory. With computers we are learning how to store all components of our culture in a more unified, single coding system, and the conversion to that new coding system has been irreversibly initiated.

To use computers in any domain, the material to be worked with must be described in binary code, for computers process information bit by bit. An irreversible action that we have commenced is to convert the coding of diverse cultural resources to binary code. First numbers and mathematical operations were expressed in binary code; then text; then images, complex chemical models, materials and structures, virtually everything. The conversion is happening and it is no more voluntary now than the completion of the sip of coffee that I initiated an instant ago. The time scale for its unfolding is far more elongated, and it may consequently, if understood, be susceptible to significant adjustment; but options for such corrective action are severely constrained, as with the burning house, and a wishful return to the *status quo ante* is not among them.

What is significant in this conversion of numerous different storage and retrieval mechanisms to one shared code is the eventual potential for cultural unification implicit in it. Currently, information is stored as text, or as mathematical expression, or as pictorial representation, or as recorded sound or image, or as physical structure or relief. The new coding that is going on translates each of these discrete systems to a binary base and its long-term cultural consequences are immense: From that shared base, root conceptions can be expressed in whichever representational form best suits the needs of the user. The mathematical relationship may start as a verbal proposition, be changed to a mathematical formula, and then to a dynamic, unfolding graphic curve.

Related to this change in the coding on which material memory can be based is another one that may be even more significant. We have lived up to now in an era in which culture, understood as the externalization of mental achievements in objective things, has consisted exclusively in the remembrance of things. To be sure, we have long been able to use objectified memory to help instruct and discipline the intelligence. Thus the young study the recorded fruits of great intelligences with the aim of informing and activating similar capacities. The objectified memories, qua objects, were inert and dumb, primarily various marks on a page in one or another form of symbolic notation.

As we translate the stuff of culture into binary code and create more and more powerful tools for working with such binary code, we are increasingly able not only to store information in external objects, but to endow certain objects with the power to process information intelligently. The basic rule of digital technology is that insofar as we can specify something in binary code, we can recreate it. Increasingly, we are learning to specify intelligent operations in binary code, and insofar as we do, we can recreate in digital technology the forms of intelligence so specified. With this, we have irreversibly initiated the transformation of a culture of remembrance into a culture of intelligence. Until the historical present, people have learned how to store all the information they need in objects external to living minds; in the historical present people have begun to learn how to process intelligently the information they need through objects external to living minds.

All culture can be coded so that it can be operated on with digital computers, and the operation of digital computers is such that it will not only allow for the storage and retrieval of information through objects external to our minds, but will also permit the intelligent processing of that information in those external objects. Thus we have a more powerful tool for storage and retrieval than those hitherto available, one that further will provide its users with intelligently preprocessed information. We have crossed the frontier and initiated irreversibly a sequence of developments that will take a long time to complete, in which the cultural potentialities of these technologies are tried and tested. Some can regret the change, but they cannot reverse it; and others, like the authors who follow here, can welcome it and work to fulfill it.

The articles in this issue of the *Record* consist of reports from beyond this pedagogical frontier, early explorations and attempted mappings of the way. In practical terms, the potentiality of binary code as a base code for multiple forms of representation will be developed steadily over time by those exploring graphical and multimedia computer-based educational resources. Likewise, the pedagogical problem encountered in shifting from a culture of memory to one of intelligence will consist of developing educational strategies through which people will learn how to control and direct the intelligent tools that will increasingly be available to them. These are the themes developed in the pages that follow. The tone is tentative and exploratory, a fitting tone for an effort the full possibilities of which will unfold only over a period of decades and generations.