"Mainmise sur le paysage"

Glenn F. Cartwright

The Symbionic Mind

People visiting exotic places learn that life has other dimensions, but typically fail to communicate the news to those who stay at home. The experience is frustrating for both parties: familiar words have new references for one side, new words have no reference at all for the other. So the travellers take to talking only to each other, for their bright proselytizing rain washes right off the backs of the ducks who live content in the old farmyard.

This is how it has been with the in-people of computerdom, returning with eyes aglow from that land of the future. We have all, these past six months, been drenched with prophecy, excitement, and warning about personal computers, and the main result has been the erection of a fictional half-world in the minds of many, where temporarily adapted images stand propped up on false fronts as we guess at what the brave new world really consists of.

Cartwright puts our mental feet on more solid ground. Basing his forecast on existing developments in psychology and medical technology (themselves astonishing enough), he builds an amazing prospect of what shall be done in our time for the human brain, a prospect that is, he can claim, no longer science fiction but science fact. It is a fascinating account of conditions our children should be made ready for.

Why, we may darkly ask, should our minds be boggled like this? The answer may simply be that, unaided, the human mind is chronically boggle-prone, in a way that the symbionic mind of 20 years from now will have rendered prehistoric.

> ...All the hopes and dreams of your race are ended now. You have given birth to your successors, and it is your tragedy that you will never understand them - will never even be able to communicate with their minds. Indeed, they will not possess minds as you know them. They will be a single entity, as you yourselves are the sums of myriad cells. You will not think them human, and you will be right.
>
> -Arthur Clarke (1953 p. 182.)

How curious it is that ideas which may have taken centuries to evolve appear in retrospect to be so simple. Each of us has experienced the "Why didn't I think of that?" feeling. It is a sad fact that though hindsight is 20/20 we are incredibly short-sighted when it comes to predicting the future.

Now, our species is not only on the verge of creating exciting new technologies, but of merging them to create a super-technology with the power to transform not only individuals but most social structures as well, including education. Yet even though we gaze upon these eventualities, it remains a difficult task to predict future trends and to see their possible implications. Despite this, it is probable that from some future vantage point, we shall look back and marvel at our current inability to seize what will appear to us then to be the simplest of ideas.

To keep in perspective this difficulty of prediction, consider the example of the simple telephone. Just over a century ago, in 1878, Alexander Graham Bell wrote:

> ...I believe that in the future, wires will unite the head offices of the Telephone Company in different cities, and that a man in one part of the country may communicate by word of mouth with another in a distant place (Hyde, 1976).

Despite the fact they were already acquainted with the technology of the electric telegraph, the idea of transmitting a human voice to the other side of the continent would have been thought ludicrous by most Victorians. And yet today, the everyday telephone is commonplace, the long distance telephone call ubiquitous, and the technology that permits each routinely accepted.

Yet a careful examination shows that we have accepted at face value a technology that has nothing to do with transmitting a human voice. No voice is transmitted across the continent.

None falls upon a listener's ear. In fact, it may be said that **no one has ever heard a human voice over a telephone.**

What we really hear is an electro-mechanical representation of a voice, close enough in inflection, tone, and accent to pass as an acceptable facsimile. It is an electronic "copy" of the original voice. Yet few of us care to think about telephone conversations this way - it is somewhat unnerving to believe we are only talking to a device which can electronically reproduce a voice so accurately as to fool listeners into believing it is the real thing. This example illustrates:

1. the disbelief potential technologies initially engender,
2. the usual acceptance of a technology once it is upon us, and
3. the shift in our belief systems and values which accompanies that acceptance.

By wiring our world to make instant communication a reality, the telephone has brought tremendous changes to society. At the same time it has changed the way in which we interact with one another: we may phone Mom more often, but visit her less. We also have to contend with certain maladapative behaviours like telephone extortion, payphone vandalism, theft of telephone service, telephone credit card fraud, telephone harassment, and obscene telephone calls, none of which were envisioned by Alexander Graham Bell when he first shouted into his prototype telephone.

While the telephone has had its own individual technological effect, the merger of telephone technology with the technologies of computers, satellites, and television has meant an even greater effect on individuals and on society. Computer communication now takes place over telephone lines, satellites link distant telephones, and videophone service is a reality in many cities. If this example is any indicator, it may be said that the social effects of technological mergers may be greater than the sum of the effects of individual technologies.

Today, new individual technologies promise to bring even further changes to humankind, and their merger will once again present us with massive psycho-social changes. Only by thinking about the psycho-social issues surrounding a new technology before it is fully upon us can we hope to deal with our future more effectively. Our past experience with the telephone may help us to keep in mind future problems associated with the creation of a new super-technology.

A tool to amplify the brain

Some might dismiss a super-technology as being just another tool. If so, it might be wise at this point to pause and reflect for a moment on the characteristics of tools. In general, tools may be divided into two classes. There are those which amplify some existing attribute, and there are those which not only amplify but actually transform the attribute. Mechanical tools, for example, fall into the first category. Pick up a hammer and the power of your arm muscles is instantly amplified. Put the hammer down, and the amplification is lost. No significant change occurred to your muscles during the short time you held the hammer. It is true that working with the hammer for a period of months might strengthen your arm muscles, but this is more the result of exercise than it is a specific function of the hammer.

Intellectual tools like microprocessors, however, whether in calculators, computers, or brain prostheses, not only amplify intelligence, they transform it. When one stops using a computer, one is left all the wiser, enriched by the understanding gained, by the knowledge obtained, and by the insight acquired from the whole experience. All these remain when the computer is switched off. Physiologically, it might be said that new neural pathways have been established; psychologically, that learning has taken place; or cognitively, that cognitive changes have occurred as a result of the interaction. But however we choose to describe the changes that have taken place, it is imperative we understand this principle: the result of our interaction with computers is qualitatively different from the result of our interaction with other kinds of tools, and the effects are both long-lasting and cumulative.

Just as the invention of the telephone extended the human voice, and computers and calculators already amplify our intelligence in a limited way (McLean, 1981a), a new invention is on the horizon that will significantly extend human intelligence. It will be quite unlike other tools we have invented, which for the most part, were external extensions of our bodies. For though computers and calculators already amplify our intelligence in a somewhat minor way, they are not yet connected directly to the human brain. A number of interfaces like keyboards, line printers, and video screens are still required to link humans with machines. In the future, however, it will be possible to build more sophisticated intelligence amplifiers that will be internal extensions of our brains. These "ethnotronic" devices will be significantly more powerful than present day computers and may even be wired directly to the human brain for both input and output. They will amplify and strengthen all the intellectual abilities we now take for granted as comprising intelligent human activity. We may call such devices "symbionic minds" (symbiotic + bionic), so named because of the close, interdependent relationships that will almost certainly exist between them and our own brains and because they may make us, to some degree, bionic (Cartwright, 1980a, 1980b; Fleisher, 1982; Takacs, 1982). Others have envisioned the same kind of device. Says Robert Jastrow (1982), founder and former Director of the Goddard Institute for Space Studies and now Professor of Astronomy and Geology at Columbia University:

> In five or six years - by 1988 or thereabouts - portable, quasi-human brains, made of silicon or gallium arsenide, will be commonplace. They will be an intelligent electronic race, working as partners with the human race.

We shall come to find such inventions truly indispensable, and we shall come to rely on them more and more, just as we now rely on a variety of devices from wrist watches to pocket calculators. To complete the symbiotic circle, intelligence amplifiers may ultimately come to rely on us, feeding upon our thoughts for data, working with us in unity of purpose, watching over our every need, and exhibiting great loyalty to us throughout our existence.

Connecting five developments

The idea of such intelligence amplifiers is not new, and the evidence which suggests that we may soon be forced to adapt to a whole new range of these tools is a projection based principally on the emerging research of at least five areas. These are the development of

1) emgors,
2) brain pacemakers or cerebellar stimulators,
3) biocybernetic communication and neurometrics,
4) artificial intelligence, and
5) biotechnology.

Let's look at each of these in more detail.

1. Emgors

The first of these is the recent appearance of "emgors" (electr**o**myogram sens**ors**) now used to enable amputees to control artificial limbs in an almost natural manner. In research being carried on, among other places, at Harvard, the Massachusetts Institute of Technology, the Massachusetts General Hospital, and the University of Alberta, the ultimate goal is to create artificial limbs that respond to the will of the patient. The trick is to find in the stump of the severed limb the brain's own natural impulse called the myoelectric signal or electromyogram (EMG), improve it through amplification or other means, and use it to control electromechanical devices in the prosthetic appliance. An obvious use would be to have it control an artificial limb called a myoelectric arm. One such battery-powered device known as the "Boston arm," developed by the Liberty Mutual Research Center in Hopkinton, Massachusetts, has been available commercially since 1969, and more than fifty were in use by 1980 (Elliott, 1980). The arm operates by electronically filtering the EMGs received from a pair of electrodes at the biceps and another at the triceps, and using the amplitudes of the smoothed signals to control the speed of the arm's motors.

In Sweden, Dr. Rolf Sorbye, head of the Clinical Neurophysiology Department of Orebro Regional Hospital has used similar principles to develop a device known as the "Swedish myoelectric hand prosthesis". The hand will be of particular use to children three-and-a-half to four-and-a-half years old, and has now been approved for supply and use in Britain by the Department of Health and Social Security (DHSS..., 1981).

At the Illinois Institute of Technology, a more sophisticated approach than that used with the Boston arm focuses on improving the control of such artificial limbs. Rather than just amplifying the raw strength of the EMG as is done with the Boston arm, a microprocessor is used to analyse the frequency distribution of the EMG waveform and use it to control the prosthesis. Still other experimental work at the University of Utah centres on analysing and using EMG's from a variety of the muscle sites scattered over the surface of the shoulder area to eliminate the "crossover" problems associated with the EMG signal which often result in imprecise movement (Elliott, 1980). In the future, even more sophisticated microprocessor technology will be used to detect, analyse, and interpret arriving EMG's in an effort to effect more natural movement of the artificial limbs. Related to this would be the refinement of tiny computers to control existing paralysed (rather than artificial) limbs (Computerised movement..., 1981). The extension of this research could allow quadraplegics to control devices other than myoelectric arms, granting them greater control over their lives by allowing them to do more of the simple things we all take for granted: close a window, turn on the TV, switch off the room lights, or type a letter. In the future, the same principles may be used to benefit everyone by allowing us to control mentally a wide variety of useful appliances.

2. Brain pacemakers or cerebellar stimulators

The second area is in the development of brain pacemakers. This work followed the creation of cardiac pacemakers and is based on much of the research concerning the electrical stimulation of the brain. The idea of electrically stimulating the brain has had its proponents (Delgado, 1961) and opponents (Myers, 1974). Penfield's original work clearly demonstrated that memories, sensations, and emotions could be evoked with slight electrical stimulation (Penfield & Rasmussen, 1950) Later experimentation with electrical stimulation revealed a number of difficulties (Sheer, 1961) Troublesome was the fact that in rats, the elicitation of particular behaviours showed little consistency and often behaviours would switch without any change in the parameters of the electrical stimulus (Valenstein et al., 1970). Electrodes themselves, though not technically "rejected", would often degrade. For example, Chang et al., (1973) found that an implanted electrode often developed a fibrous capsule as a result of tissue reaction.

Another problem was that electrical stimulation stimulated a large number of neurons at once. There seemed to be little way of selectively stimulating certain neurons electrically. Because of this, it was argued that since neuroreceptors responded selectively to certain chemicals, chemical stimulation of the brain would provide richer, more easily controlled, and more easily replicated results (Myers, 1974). This objection seems to be fading somewhat, as microprocessor technology together with improvements in biocompatible surfaces, component miniaturization, and microsurgical procedures refine the techniques of electrical stimulation.

Despite the difficulties, extensive work in the area resulted in the creation of cerebral pacemakers which further refined the techniques of tapping into the brain directly. Devices known as cerebellar stimulators have been implanted in spastic children to help them achieve some measure of control over their muscle functions. In Florida, just such a device was installed in a seven-year-old boy to reduce the spasticity brought on by too much muscle tension. The pacemaker stimulates his muscles causing them to relax and allowing him to control them voluntarily. In San Diego, California, a nineteen-year-old victim of cerebral palsy has small electrodes implanted at the base of her brain, wired to a cerebellar stimulator. The stimulator acts as a sort of brain pacemaker enabling her to lead a more normal life.

In general, most pacemakers are of the self-regulating variety, but other kinds of pacemakers exist which can be activated by the therapist or by patients themselves and these are now used in a variety of situations. For example, there is a small model that can be implanted under the scalp to stimulate certain parts of the brain when directed to do so by radio command. The technique was described some years ago by Dr. José M.R. Delgado, now at the Centre Ramon y Cajal in Madrid (Renaud, 1978), who in a dramatic demonstration, achieved fame by pressing a button to stop a charging bull. The button activated a radio signal to a pacemaker implanted in the bull's skull designed to alter its charging behaviour. In humans, such mental pacemakers are now being used to prevent patients from falling into deep depressions, to avoid epileptic seizures, and to reduce intractable pain. At Tulane University in New Orleans, several mental patients who suffer from psychosis and for whom chemotherapy has failed, have been fitted with brain pacemakers to help them on the path to normal behaviour. The controversial technique has been used with neurotics, schizophrenics, and others who have experienced the feelings of extreme anger often associated with psychosis or violent behaviour. Reportedly, many have been able to leave hospital for the first time in years and have begun to lead reasonably normal lives (Heath, 1977). Other cerebellar stimulators have been implanted as brain pacemakers to minimize the spasticity and athetosis associated with cerebral palsy (Cooper et al., 1976). Though the technical perfection of these interfaces and their evaluation pose many problems (Check, 1978), the mere existence today of simple versions of cerebellar stimulators for specific medical problems points the way to a potentially bright future for the more complex models of tomorrow.

3. Biocybernetic communication and neurometrics

In the third area of development, biocybernetic communication and neurometrics, experimental work is underway in an attempt to interpret brain wave patterns to link them to specific thoughts. At Stanford University, researchers were able to have a subject hooked to a computer screen move a white dot about simply by thinking about it (Pinneo et al., 1975) This work was continued by the Defense Advanced Research Projects Agency (DARPA), presumably because the development of such technology would have vast military implications. It has been reported that the U.S. Air Force has trained subjects to control their alpha waves in order to send Morse code messages which could be picked up by a scalp-monitoring machine and fed into a computer (Lowther, 1980).

In the area of neurometrics, the study of evoked-response potentials (EPs) in the cortex has produced interesting results. These are achieved by measuring minute voltage changes that would be produced in response to a specific stimulus such as a light, a bell, or a shock, but which would be of such small amplitude as to not show up on a conventional electroencelphalogram (EEG). An averaging computer sums the responses over time to make them stand out against background noise. Since the background noise is random, it tends to be cancelled out. Through the use of this technique, it has now been established that the long latency response known as the P300 wave (positive potential, 300 millisecond latency) is usually associated with decision-making activity. Though the wave appears after each decision, it is often delayed when a wrong decision is made. Theoretically then, it should be possible to construct a device to warn us when we have made a bad decision, to alert us when we are not paying attention (a boon to air traffic controllers) or to monitor general states of awareness (Youcha, 1982). It is also possible using EPs to distinguish motor responses from cognitive processes, and decision-making processes from action components (Taylor, 1979; Stine, 1979; Selden, 1981; Stein, 1981). Because of its ability to check on active brain processes, it is thought that EPs may do for physiology what computed tomographic (CT) scans did for anatomy (Ziporyn, 1981a). As its objectivity (patient cooperation is not needed) and non-invasiveness come to be appreciated, more and more clinical applications are beginning to appear (Ziporyn, 1981a; 1981b; 1981c), and it is likely that the number of non-clinical applications will also rise.

One obvious goal of such a technological development as biocybernetic communication would be to use thought to control a wide variety of appliances. The possibilities would appear to be limitless. For example, if thought is a form of energy, with universal "field" properties amenable to scientific research (Dean, 1975) then it may be possible to harness thought to facilitate a wide variety of human activities from controlling simple pocket calculators to complex machinery like army tanks (Cartwright, 1981b). Imagine the utility of a pocket calculator if one could operate it by just thinking about the numbers rather than pushing corresponding buttons. In fact, almost any device which now exists would be intrinsically more useful were it under the direct control of the human brain. The extension of this kind of research might eventually result in mental communication between individuals and machines and even between individuals, in a manner similar to telepathy, but based on proven scientific principles and sophisticated technology.

4. Artificial intelligence

The fourth area, and it is a broad one, is that of artificial intelligence. Though this sounds a strange term to anyone unfamiliar with it, scientists around the world working in the area of artificial intelligence are studying pattern recognition, problem solving, and voice comprehension with a view to reproducing these abilities in computers. The tiny chess-playing machines which can now be purchased in local stores are a spin-off of this research (Hunt, M., 1981). This work is now becoming more publicized and a number of rather good popular summaries have appeared recently (Hoover, 1979; Stockton, 1980; "Artificial Intelligence", 1982).

5. Biotechnology

Less well known is the work in the area of biotechnology. In small laboratories, scientists are now at work in an attempt to use genetic engineering principles to construct tiny biological microprocessors of protein or "biochips" (de Rosnay, 1981; "Futuristic computer biochips...", 1981; McAuliffe, 1981; Posa, 1981; "Whatever happened to molecular electronics?", 1981). The advantage is that by using the techniques of recombinant DNA, very small devices (VSDs) can be assembled with great precision.

> The recent advances in biotechnology, coupled with simultaneous scaling down of electronic devices, has created speculation that protein macromolecules of living things may, in nature, function to transfer electrons in a manner analogous to device function. Moreover, these macromolecules in nature are often highly oriented arrays on biomolecular lipid membranes or in helically oriented filaments, subassembling according to specific charge patterns on their surface. Our intention has been to develop means of organizing such molecules on non-biological surfaces for the microfabrication of electron devices (McAlear & Wehrung, 1981a).

Today, tiny circuits are etched in silicon using optical lithography or electron-beams. But the creation of biochips with 10-25 nanometer features (a nanometer is one billionth of a meter) would represent about two orders of magnitude smaller than current optical lithography limits, and would be smaller than that achieved by electron-beam or X-ray lithography (Butts, 1981). In fact, this would mean that ultimate packing densities (i.e. the number of transistors that can be packed into a given area) would no longer be limited by an etching tool, but for the first time would be determined by the characteristics of the protein material itself (McAlear & Wehrung, 1981b).

Unbelievable as it may sound, such biochips may even be designed to assemble themselves.

> At the molecular scale, a radically different approach to device fabrication based upon self-assembly may be possible. Here devices are constructed molecule by molecule, driven by thermodynamics and by the unique chemical properties of the individual molecules. **The existence proof for self-assembly of extremely complex functional systems is life.** The biochemical organization of living cells is very different from what would be desirable in a molecular electronic device, but molecular biology and biochemistry offer a model upon which to base the development of self-organizing systems. Furthermore, the new techniques of recombinant DNA and genetic engineering now offer the tools required to fabricate self-assembling molecular "devices" with electronic properties (Ulmer, n.d., emphasis added).

All this is rather technical. What does it all mean? It means that if biochips can be successfully constructed, it is likely they will have higher density and higher speed and will consume less power than conventional chips. This in itself will be no mean achievement because of the continuing reduction in circuit size to the point where some are now below the size of a living cell. For example, though the diameter of a human blood cell is eight microns (thousandths of a millimeter), some two micron diameter components are now reported in use and experimental work continues with parts a half a micron across or less (Sweetnam, 1982). Hewlett-Packard has now announced the creation of a silicon chip with the equivalent of 660,000 transistors packed on a single quarter-inch square chip ("Just how small...", 1982) and new chips of gallium arsenide promise to increase current computer speed tenfold (Craig, 1982). Successful though the silicon chip is, new circuits the size of molecules are already being envisioned which could significantly damage the silicon chip industry and ultimately lead to the creation of a molecular computer (Angier, 1982).

Biochips would have a greater probability of successful implantation in the cortex owing to their higher degree of biocompatibility. Already, enzymes can be combined with electrochemical sensors to produce electrodes that can be used as biosensors (Vadgama, 1981). And now, one company has already received a grant from the National Science Foundation for a feasibility study of the creation of a direct interface between the central nervous system and an integrated circuit. Their initial plan calls for increasing the number of effective electrodes from an 8 x 8 platinum array currently used in clinical trials to an array with 100,000 electrodes. Such technology will depend heavily on the use of an implanted integrated circuit and state-of-the-art microfabrication techniques. The actual device will consist of electrodes connected to an interface of cultured embryonic nerve cells which can grow three-dimensionally and attach themselves to mature nerve cells in the brain (EMV Associates, 1981; "The next generation...", 1981). Ultimately, the provision of the appropriate set of genes could enable the chip to repair itself, DNA codes could be used to program it, and enzymes used to control it (Biotech..., 1981). Though the immediate medical goal is to produce a more effective visual prosthesis, the technique, if successful, has wide-ranging ramifications.

The symbionic mind

The handwriting is on the wall; these five areas have much in common. For the most part, they deal with the brain directly, with thought processes individually, and with intellectual activity primarily. They are steadily converging. And despite the difficulties with some of the implantation techniques (Valenstein, Cox, & Kakolewski, 1970; Chang et al., 1973; Valenstein, 1978), once a merger is effected culminating in a routine way of interfacing with the brain either directly using implanted electrodes, or indirectly by picking up brain waves with external sensors, the symbionic mind will have been born.

The symbionic mind may be defined as any apparatus consisting of some useful device, interfaced with the human brain, capable of intelligent action. The most difficult task in its construction will not be the creation of useful mind-expanding devices, for such simple intelligence amplifying devices like calculators and computers already exist; the most difficult task will be the design and construction of the interface unit required to link these devices to the human cortex. Such a complex interface will no doubt represent the major component of the symbionic mind, and the creation of a wide range of standard and optional accessories to attach to it will probably prove to be a comparatively easy task.

Such auxiliary brain prostheses or symbionic minds will be used for appliance control, computation, monitoring of particular body functions, problem-solving, data retrieval, general intelligence amplification, and inter- and intra-individual communication. The ultimate revolutionary advance may even be the direct, electronic transmission of the most elusive entity of all, human thought.

The importance of human thought and its relationship to communications technology has been noted by Roger Sperry (1965), F. P. Hixon Professor of Psychobiology at the California Institute of Technology.

> Ideas cause ideas and help evolve new ideas. They interact with each other and with other mental forces in the same brain, in neighboring brains, and, **thanks to global communication,** in far distant, foreign brains. And they also interact with the external surroundings to produce in toto a burstwise advance in evolution that is far beyond anything to hit the evolutionary scene yet, including the emergence of the living cell (emphasis added).

And why should the direct transmission of thought prove to be so difficult or unimaginable? Writing from a psychoanalytic point of view, Gorney (1981) believes that

> ...there is on the human agenda a current shift toward greater cooperation and high social synergy which we could recognize and foster through modern communications...

Though he mentions no specific technology, it is interesting to note that the communications networks are already in place: the only missing link is the direct input/output to and from the human cortex. While no such symbionic minds yet exist, technological progress in the component areas suggests that such interfaces to the human cortex, using sensors and/or direct implants, coupled with microprocessor technology, may become a reality in the future.

Assuming that their development will take place as a logical extension of the current work in the five research areas summarized above, the question to be explored is, "What effect will generalized brain prostheses have on education, on child development, on teaching behaviour, on life satisfaction, and on the sharing of education in the community?"

Capabilities of the new mind

To answer that question, we must first explore the possible uses to which the symbionic mind will be put. One use might be to improve human memory. In fact, the building of such symbionic minds may prove to be mandatory in the future, if we are to improve the species and extend our own lifespan. Inadequate memory remains a serious problem with an extended lifespan, as Arthur Clarke (1973) has pointed out in his Profiles of the Future. The human brain may become filled with too many memories.

> ...even if we can keep the brain alive indefinitely, surely in the end it would be clogged with memories, overlaid like a palimpsest with so many impressions and experiences that there was no room for more? Eventually, perhaps yes, though I would repeat again that we have no idea of the ultimate capacity of a well-trained mind, even without the mechanical aids which will certainly become available. As a good figure, a thousand years would seem to be about the ultimate limit for continuous human existence - though suspended animation might spread this millennium across far longer vistas of time.

It is easy to see how people with failing memories might benefit from the mechanical aids of which Clarke writes - in this case tiny mind prostheses or "add-on" brains with extra memory storage - symbionic minds. Such devices will prove invaluable, not only to senior citizens, but to all of us. Never again will memories fail with age. Rather they will improve with longevity due to better access to a larger memory store, and even the feeling of "having something on the tip of the tongue" may disappear forever.

Symbionic minds will do more than just improve memory, but as yet one can only speculate as to their full range of uses. Nevertheless, the possibilities appear to be endless. Because the symbionic mind will be able to interpret our thoughts, our very wishes will become its commands. Thus it will be able to take dictation directly from our thoughts, improve them through editing, and like the word-processors of today, rearrange whole paragraphs, perform spelling checks, and supervise the typing of final documents. It will, in effect, assist us in the more routine aspects of our thinking, freeing us for more creative thought.

To some degree, the human brain may be limited by its small number of input senses. On the other hand, it really isn't known to what extent the brain could handle more inputs, were they available. But a symbionic mind connected to the brain to amplify its abilities, improve its skills, and complement its intelligence, could be used to handle additional sensory inputs, and to make low level decisions about them, discarding irrelevant data, and passing on more important information to the brain itself.

The symbionic brain will provide a sophisticated interface between us and a wide variety of household gadgets. One can already buy photoelectric switches and sound switches at most local electronics supply stores to turn appliances on and off with the beam of a flashlight or the sound of a voice. The symbionic mind will provide a "thought switch" to enable us to control appliances merely by thinking about them.

The symbionic brain will turn lights on and off for us, activate television devices and switch channels (feeding the signal directly to the brain), answer telephone calls and initiate them, keep household inventories, and order the groceries. It will guard us from a number of dangers and protect us in a wide variety of situations. At a party it will monitor our blood alcohol level and warn us when we have had too much to drink. It will keep an eye on other bodily functions including digestion and blood sugar levels, and warn us of impending illness, undue stress, or possible heart attacks. It will guard us while we sleep, listening for prowlers, and sensing the air for smoke. It will attend to all household functions and perhaps will ultimately direct the activities of less intelligent household robots which are sure to have come into existence by that time. It will share with us its vast memory store and its ability to recall information virtually instantly - information we thought we had forgotten. It will do math calculations, household budgets, business accounts, and even make monthly payments for us automatically. It will update its own information daily by scanning a number of information sources, perhaps listening to its own information channel, perhaps digesting local newspapers, sifting for information which it feels it should bring to our attention, helping us make sense of the "blips" of information which Toffler (1980) argues characterize the Third Wave "blip culture" in which we live. As mentioned, it will provide a whole new dimension of living to quadraplegics allowing them to perform many of the routine daily tasks essential to life, and restoring to them some measure of control over their lives.

In the future, it may be possible to build into the symbionic mind totally artificial senses and connect them directly to the brain. These artificial senses would simulate most of our existing senses, but would bypass currently available receptor organs. For example, why shouldn't we be able to receive television pictures directly without the aid of a TV receiver? Conventional TV sets are really only converters: the broadcast signals we in our natural state are unable to receive, they convert into visual signals which can be input through our eyes. From the eyes, the signals are converted to electrochemical impulses to be sent to the visual cortex for analysis. In this way, McLuhan (1965) was right when he called media the extensions of our nervous system: they extend our wiring enabling us to process information originally encoded differently. Radio, then, becomes an extension of the ear, and television an extension of the eye.

Now imagine if you will, a small device which receives TV signals, but instead of displaying them on a video screen, channels them through your symbionic mind directly to your brain. You would still have the sensation of "seeing" the pictures, yet your eyes would be freed for watching other things. Such devices would not be limited to television, but might include radio and telephone reception as well. In all these instances, the normal sensory inputs of eyes and ears would be bypassed. Already, preliminary work in this direction has been undertaken at the University of Florida to find ways of implanting up to 100,000 miniature photovoltaic cells to stimulate previously unused parts of the retina in cases of retinal blindness. In the auditory domain, patients at the Los Angeles Ear Research Institute have been fitted with electronic ear stimulators to stimulate auditory nerves in an attempt to improve hearing. Other researchers at the University of Utah-Salt Lake City, the University of California-San Francisco, Stanford University, the University of Washington-Seattle, and abroad in Australia and Austria hope to bypass the auditory nerve completely by developing a device that would convert sounds into electrical impulses which could then be fed directly to the brain's auditory centre.

The symbionic brain will change the entire realm of communications as we know it today. Merely thinking of someone you wish to talk with by telephone will initiate a search by the symbionic mind to locate that person anywhere in the world and establish direct contact. Though physical telephones will be avoided, the two symbionic minds will be in direct communication over the regular telephone network, and thoughts will flow between beings in seemingly telepathic fashion; indeed this may be the closest we will ever come to true telepathy.

From individuality to a shared, global consciousness

Because we will be in potentially instant communication with one another, with thoughts flowing both ways at will, it is likely that our whole concept of individuality may change. An early fictional account (Clarke, 1953, p. 172) provided the analogy:

> Imagine that every man's mind is an island, surrounded by ocean. Each seems isolated, yet in reality all are linked by the bedrock from which they spring. If the ocean were to vanish, that would be the end of the islands. They would all be part of one continent, but their individuality would have gone.

Though some might abhor any change in what we have come to know as individuality, the change might prove to be positive. It may signal a new and different relationship among the peoples of Earth and may represent the beginning of true global consciousness. With it will come the promise of increased empathy and understanding, a new sense of purpose for humankind, and a fresh appreciation of those things that make us uniquely human.

If our concept of individuality changes, so might what we have come to know as consciousness. But consciousness itself is poorly understood. Though definitions of consciousness abound, its true nature remains unknown. There is some agreement, however, as to certain of its properties: that it develops within the individual, that it includes awareness, and that it consists of various levels (Restak, 1979; Taylor, 1979). Less widely accepted is the notion that, at the species level, there may well have been a time when individuals did not experience consciousness as we know it (Bucke, 1901; Jaynes, 1976) and that consciousness evolved and continues to evolve. If consciousness continues to evolve, we might well ask what is the next step in that evolution, what is the final goal, and what role might new symbionic technology play in reaching that goal?

The study of human consciousness often seems inextricably intertwined with the invention of writing. It has even been suggested that the technology of writing contributed directly to the origins of consciousness by weakening the hallucinatory auditory control prevalent in ancient times (Jaynes, 1976; Hilts, 1981; Gliedman, 1982). Whether or not one accepts this interpretation, it must be recognized that it was only with the invention of writing that ideas could be stored relatively permanently and accurately, to survive brain death, and be passed on to other members of the species. Libraries became the collective repositories of human thought. Individual consciousness, combined with the technology of writing, was the first step on the road to global consciousness.

The second step toward global consciousness is the new level of awareness we have been indirectly creating through modern, electronic communications. Futuristic as this may sound, some evidence for this new level of awareness already exists, and it is tied directly to the growth of communications technology. As we have steadily wired our world with telegraph, telephone, and radio and television networks, our consciousness of other problems in different parts of the world has greatly increased. And now, new networks of computer communications promise to transcend both time and space, creating new patterns of communication behaviour and even altered states of communication (Vallee, Johansen, & Spangler, 1975). Television coverage of the Vietnamese War proved that modern communications technology brings an immediacy to world events that is hard to ignore, and often culminates in improved cognitive awareness, increased empathy, and raised consciousness. It is on this foundation of communications-induced global awareness that the beginnings of shared or symbionic consciousness will ultimately rest.

Today, we recognize that consciousness is less a **product** of individual neurons than it is a **process** of large numbers of neuron assemblies. Nevertheless, it can be argued that individual neuron assemblies must have some part to play, however small, in the larger activity of consciousness. So too, we may find that a large number of individual symbionic minds, interconnected to facilitate data retrieval and enhance communication among individuals, may also generate as a by-product a third level of awareness: symbionic consciousness. Such symbionic consciousness may be defined as the facilitation by cortical prostheses of a qualitatively new level of electronic, collective, and temporally-shared consciousness. Each participating individual will have some contribution to make, however small, to this larger, shared consciousness. In much the same way as the large mainframe computers of the 1970's appear to be evolving into networks of smaller computers in the 1980's (distributed computing, which according to Simpson (1982) may represent the beginning of a rudimentary world brain). So too the human cortex appears to be searching for ways to connect itself to others to distribute its own awareness and perhaps ultimately share in a larger global consciousness.

From alienation to synergy

To some extent this may signal a restoration of lost values and a lessening of the alienation of which Sheridan (1980) has written. As McLuhan (1980) has said:

> It might even be said that at the speed of light man has neither goals, objectives nor private identity. He is an item in the data bank - software only, easily forgotten - and deeply resentful.

To some extent, the explosion of data has contributed to this alienation. For example, while the punched computer card which we all remember being admonished not to "fold, bend, spindle, or mutilate," stores about 4 bits per square centimetre, new techniques of optical recording allow laser beams to write up to 150 million bits in the same area (Hecht, 1982). Simply trying to deal with this increase in information can be alienating. But the symbionic mind may provide us with the additional hardware with which to deal with this dehumanizing eruption of data in the real world that has tended to reduce us to insignificance. The symbionic mind will improve our ability to manipulate and act on data in the surrounding environment, and promises to bring to us added importance and a feeling of control culminating in improved self-esteem and a renewed sense of identity and purpose.

It has already been suggested that the creation of symbionic devices will greatly increase our intellectual function. But the symbionic mind by definition will be more than just another tool. It is likely that the interaction between individuals and their symbionic minds will be synergistic - each will act with the other to create a new effect greater than the sum of their individual effects. Thus may humans and machines be wedded, and the offspring of their union may be a synergistic system unlike any other. We may find ourselves dealing, in the future, with whole new levels of intellectual functioning. Far from being a crutch-like device, the symbionic mind will contain sophisticated technology with its own degree of machine intelligence designed to enhance human abilities, and to propel us far beyond our innate potential.

No doubt for some the prospect of symbionic minds sounds at best like something out of a science fiction magazine. It is, however, less a question of science fiction than of science projection. It is a projection of what can be seen evolving from the recent scientific advances concerning the creation of artificial intelligence in computers, and the new medical technologies which now allow us to tap directly into the human brain. The symbionic mind will not be a truly separate brain but will be an extension of us, of our very being. It will not seem to be foreign to us in any way, nor will it pose to us any kind of threat by trying to take us over any more than would our own brain. The symbionic mind will be as much a part of us as a hand or an eye, and it will seem to us simply our own brain doing the thinking. It will be transparent to us. We will not be aware of any separate entity, nor of any other change except an increased ability to perform those intellectual tasks we have always performed, and a new capability to accomplish those which were previously impossible. The new symbionic mind will act purposefully and willfully, but always on our behalf and at our direction. It will be our constant companion and friend, conscience and alter-ego. The development of the symbionic mind, the culmination of our physical rewiring, will mark the next step in the evolution of our species to a higher plane of existence, and the dawn of a new era.

The benefits and the cost

It has been said that knowledge is power. Using symbionic technology to permit individuals instant access to large amounts of data may indirectly function to preserve certain democratic ideals by preventing the control and manipulation of data by a few unscrupulous or power-hungry individuals.

Other beneficial results may be less obvious. There is a very real possibility that such increased awareness may help us to preserve those things that are uniquely human in an increasingly dehumanizing environment. We may at last be able to use technology's potential to enhance those features that are best represented by human values. We may find that this kind of technology can be used to foster such ideals as honesty, altruism, and brotherhood. The linking of individuals to facilitate communication might very possibly change the way we relate to one another, increase our empathy and understanding, and improve world harmony.

The prospect of creating a global consciousness raises a number of questions for society, like "To what extent is global consciousness desirable? In what ways can each individual mind contribute? To what extent may such a contribution to the larger consciousness prove to be beneficial (or harmful) to the individual?"

Though the improvement of communication among societies may give rise to a higher level of awareness, it may also bring with it a whole new range of psychiatric and behavioral problems at the individual level. When Abraham Lincoln was assassinated, it took twelve days for the news to reach London. Yet within hours of John F. Kennedy's assassination, an estimated forty percent of the American population suffered some physical complaint as a result of the news, with symptoms ranging from loss of appetite to insomnia. Any new, large-scale technology has the potential to bring with it great stresses in our social system, and the possibility of great social change. Witness the anguished rash of suicides that followed the highly publicized December 8, 1980 murder of Beatle John Lennon outside his New York City apartment. Telephone crisis lines rang incessantly, and several therapy groups had to be established to help many of the grief-stricken fans over their upset.

Symbionic technology, with the possibility of electronically linking individuals to large data bases and to each other, paradoxically also has the potential of isolating each of us physically, spiritually, and emotionally. This could be a damaging eventuality, for as Zimbardo (1980) has written, "There is nothing more destructive of physical and mental health than the isolation of you from me, of us from them." For psychiatry, the message is clear: the symbionic technology of the 21st century may bring with it new kinds of emotional disturbance, and new kinds of mental illness. If hysteria characterized the 19th century, and anxiety the 20th century, the 21st century may well be the century of what I have called the "symbionic syndrome": technologically-induced disaffect characterized by increased existential loneliness, and feelings of alienation, powerlessness, and disembodiment (Cartwright, 1981b).

Child development

The impact of symbionic technology on child development promises to be great. This will not be because we will be turning children into absolute geniuses, but more likely because it will provide opportunities for children to display the intellect, the cleverness, and the abilities which **they already have.** The symbionic mind will provide an electronic interface to enable children to accomplish intellectual tasks of which they are already capable, but are perhaps unable to perform due to maturational factors.

For example, for many years it has been thought that some grade one children who are intellectually capable of reading are unable to do so because of maturational factors. They may be unable to exert the necessary control over their eye muscles in order to read. The symbionic interface may enable the child to minimize the effect of these maturational factors and free the natural mind to accomplish those things for which it is intellectually ready. Not only would such an eventuality foster intellectual development, allowing it to take place when the child is intellectually ready, but it might also alleviate possible frustration and potential behavioural problems in the classroom.

Piaget (1953; 1970) believed that cognitive development should proceed at its own pace, and that no attempt should be made to speed it up. Others have disagreed (J McV. Hunt, 1961; Engelmann, 1969) and have argued in favour of accelerating children's progress through the developmental stages. But speeding up development significantly may in fact prove to be impossible, or if possible, may result only in superficial learning and not true understanding (Ginsburg & Opper, 1969; Kamii & Dermon, 1972). Almy et al., (1966, p. vi) summed it up this way:

> In the realm of education... students should be allowed a maximum of activity on their own, directed by means of materials which permit their activities to be cognitively useful. In the area of logico-mathematical structures, children have a real understanding only of that which they invent themselves, and each time that we try to teach them something too quickly, we keep them from reinventing it themselves.

But an alternative view is that symbionic minds will tap the innate potential of the cortex; they will unleash cognitive development perhaps already present but masked by maturational or other factors. They may not speed up progress through the developmental stages, but may enrich each level qualitatively.

For example, it is well known that prenatal cortical development proceeds incredibly rapidly. One estimate is that at 80 days before birth, the brain is wiring in some 500,000 connections per minute. And though significant deceleration of this development is evident from birth onward, the rate at which children learn remains nothing short of remarkable. The task of language acquisition is in itself a monumental feat. Yet for decades, we have failed to grasp the extent and the signficance of cognitive development during the first few years of life. Keeping children away from school until age five is evidence of our failure - if we do send them prior to age five we refer to it as "day care", as if little can be learned or taught during that period.

This is a serious error but an understandable one. We really don't have a full appreciation yet of what children can do in schools before the age of five. Some developmental tasks have been described but the majority of day care centres still focus around blocks and sand boxes and activities of that sort. With some exceptions (e.g. Papert, 1980; Golden, 1982), the rich intellectual world of computing has been, for the most part, unavailable to children up to now. Neither have we understood how to capitalize on the innate skills and abilities of children in order to facilitate development. The trick is to find ways of maximizing those skills and abilities which already exist in the behavioral repertoire. It is interesting to note that many of our discoveries about human development have attended the creation of a specific apparatus allowing particular kinds of observation. Using an apparatus similar to that originally designed by Siqueland and De Lucia (1969), Kalnins and Bruner (1973) studied whether or not infants just a few weeks old could focus pictures by sucking on a dummy nipple. Since the sucking response is well-established in infants of this age, the apparatus represented a clever way of "interfacing" with the infant by capitalizing on this well-established response in the behavioral repertoire. It was found that infants from 5-12 weeks of age were indeed able to focus the projector in order to watch silent moving pictures. That is to say, the infants were found to be capable of exerting some measure of voluntary control (in which infants are usually thought to be deficient) to produce a required outcome.

> What is striking about the adaptation we have observed is its swiftness in establishment and its equally great swiftness in being transformed when conditions change. In all the above respects it seems reasonable to suppose that, just as the sensory-perceptual and sensory-motor capacities of the very young infant have been seriously underestimated because of failure to use the correct behavioral repertory for measurement, so too, and for the same reason, has the voluntarily-controlled problem-solving activity of the infant been similarly underestimated. The more general significance of the patterns of infant competence must - we believe - be re-examined to understand better the function served by human infancy and the manner in which it makes possible uniquely human adaptation (Kalnins & Bruner, 1973, p. 313).

Giftedness

Those children with keen minds who find school boring - the gifted - may be freed by their symbionic minds to race ahead to new areas of thought and discovery, thereby eliminating the boredom that often permeates their lives.

In fact, even though the benefits of symbionic technology will surely accrue to all, one could argue that it may very well be the gifted students who will benefit most. Up to now too little attention has been paid to the education of the gifted. When their special needs have been recognized, too little has been done to accommodate them (Telford & Sawrey, 1977). Teachers, parents, and others who work with the gifted have often found themselves frustrated, suspecting that the gifted children in their care were bored, and were wasting both their time and their talent. Unfortunately, up to now, little could be done about it, because of the lack of special facilities, and because of the general lack of knowledge on how best to meet the needs of the gifted. Yet the realization has been steadily growing that special facilities for the gifted, and special attention, is not unwise, nor unfair, nor necessarily unequal (Goldenberg, 1979). As de Bono (1980, p. 219) asked:

> Does the concept of equality demand that a big man be fed no more than a small man or that both be

> equally satisfied with their food? So special attention to the gifted is not contrary to egalitarianism.

We might note in passing a parallel problem in the use of computers in education. If we did not know what to do with gifted children in education during past years, we knew even less what to do with computers. As Papert and Solomon (1972, p. 9) observed a decade ago:

> ...How strange, then, that "computers in education" should so often reduce to "using bright new gadgets to teach the same old stuff in thinly disguised versions of the same old way."

It is incredible that the gifted with great human potential, and computers with infinite machine potential should both have suffered the same fate, historically, at the hands of educators (Cartwright, 1981a). But the way seems clearer now, and there is little doubt that the emergence of inexpensive microcomputers in education will be a boon to the gifted, allowing them to begin to extend their intellectual power in ways previously unimaginable.

Evans (1979) recognized this phenomenon with respect to calculators and projected it to computers:

> But there **is** a kind of bright child, usually coming from an educationally and culturally upmarket home, who takes to the calculator like a duck to water, exploring its myriad permutations for sheer pleasure and, in doing so, acquires an intuitive grasp of fundamental mathematical concepts. Math teachers are already familiar with this small but interesting breed who stand out so markedly from the rest of the class... If this trend becomes at all strong, we could find ourselves with a generation of children sharply divided between those who have amplified their own brain power with that of the computer and those who remain wedded to the haphazard ignorance of the past (pps. 143-144).

Exponential acceleration

Consider what the upper limits might be if a symbionic mind were available to a person already gifted with superior intellect. On the surface one might expect, as we always do, a linear relationship: a symbionic mind of a certain size might be expected to increase brainpower by x times. But this may not be how it will work at all. The gifted who participate in such a synergistic union may experience an intellectual leap more exponential than linear. Such cortical prostheses may help the the gifted soar to new heights of creativity, imagination, and invention with no upper limits in sight (Cartwright, 1981a).

To illustrate the concept of exponential growth, Evans (1979) asks us to imagine taking a piece of paper and folding it over on itself fifty times. Ignoring the difficulty of doing so, how thick would the resultant wad of paper be?

Because most of us, mathematicians and computer programmers included, are more used to linear change and are usually unaccustomed to thinking exponentially, we are surprised to learn that the "stupendous block of paper will have pushed far above Everest, right out of the atmosphere, past the moon, beyond the orbit of the planet Mars and into the asteroid belt. Human beings just do not have a conceptual experience of the exponential." Computers will provide that experience.

There is every indication that high technology in the hands of the gifted might well produce more than we expect, and more than we can even imagine at this point in history. As Christopher Evans (1979, p. 245) has pointed out:

> ...it is a characteristic of any race which involves exponential acceleration that the man who gets off first continually pulls away from his opponent.

In the future, it may very well be the gifted who "get off first" and who continually pull away because of their intellectual exponential acceleration.

Implications for teaching

The emergence of microcomputers signals the first step in unlocking not only the intellectual powers of the gifted, but of all of us. Though the case has been made here for symbionic technology for the gifted, similar arguments can be made for any subgroup of the population. Symbionic technology has the potential to enhance human achievement, whatever its level, even among the intellectually handicapped.

There is every indication that educational computing will contribute to a change in the way in which we learn. The current growth of microcomputers in the schools foreshadows this trend. And symbionic technology will extend it. If symbionic technology changes the way we learn, it will also change the role of the student, the role of the teacher, the role of the school, and the role of the individual in society (Cartwright, 1982). In the future, the kind of activity which stimulates problem-solving activity and creativity rather than rote-learning will become paramount. Learning tasks which emphasize structure rather than detail will be highlighted, and there will be a greater move towards conceptual games and simulations. Because the nature of personal computing encourages individual problem-solving, more and more students will work on their own using their own computing resources to solve problems, generate solutions, and retrieve data.

Fifteen years ago, the per capita consumption of electrical circuits was 3, today it is 10,000. More and more integrated circuits are showing up in every aspect of life from automobiles to homes. In fact, it has been predicted that integrated circuits will permit houses of the future to become sensitive to the needs of their occupants (Mason & Jennings, 1982). Within the decade, the annual per capita consumption of electrical circuits will rise to 2 million (Mitchell, 1982). A large proportion of this will be due to the phenomenal growth of personal computing. Microcomputers now provide individuals with whole new powers. For the first time, we are able to process data externally. As McLean (1981b) has noted:

> Until the early 1950's, no significant information processes existed outside of the human skull. Even with the development of computers since then, the only portion visible to the non-specialist was the printed result. The printed paper output related to the information that the machine had processed, not the processes employed by the computer in producing it. The processes remained a mystery.
>
> It is only recently that microelectronics developments have made available, inexpensively, the information processing capabilities of computers. It is only now that the general public can hope to become involved with the idea of information processes in machines. Thus, the significance of microcomputers is the democratization and popularization of information processes they make possible. Now, through public education's involvement with microcomputers, non-specialists may have first-hand experience with information manipulation processes outside of their own (or other human beings') head.

This is a subtle yet important idea, and one that belies the notion that the impact of microelectronics simply lies in greater access to information services and larger data banks.

The implications for classroom teachers are vast. Teachers will become true "managers of instruction" and "resource persons" helping only with specific problems, and complementing more personal forms of instruction. We will not only change the way we teach, but what we teach as well.

Whole areas of curriculum will have to be re-evaluated and perhaps even replaced. We will have to ask ourselves, "What facts do we teach to pupils who are already in communication with vast data banks? What math tables do we teach to those who can already perform instant error-free calculation? What library skills will be needed by children who already know how to summon any document instantly to their view? What languages do we teach to those who have access to rapid machine translation? What letter writing skills will be required by students who are already in instant world-wide communication with one another?" (Cartwright, 1982).

These developments cannot help but change the role of schools as we know them. For a number of years, educational philosophers have talked about the changes coming in schools, and of ways of deschooling society. Now for the first time appear ways in which new technology may make such eventualities plausible realities.

The implications for society

It has already been suggested that the dissemination of personal computing power to individuals will serve as a check on the imbalance which now exists in the heavy use of computers by government and industry. This is obviously a desirable goal in any democratic society. (The converse is also true: we may expect totalitarian regimes to resist personal computing and symbionic technology because of the intellectual power it may restore to the people. Telephones, because of their power of allowing people to communicate, were similarly resisted, and many communist countries today still have only one telephone at the local post office in many towns.) This, coupled with the qualitative change that individuals will experience not only in being able to process data but to examine those processes, will prove to be a deeply satisfying and life long experience.

For a number of years, social scientists have been worried about the increasing leisure time people have due to improved working conditions, a shorter work week, and automation. The prospect of filling one's leisure time in a meaningful and productive way seemed elusive to many, and the worry was that society would be unable to help people structure their leisure time in a meaningful way. The existence of personal computing, however, changes the outlook. Now, more and more amounts of leisure time may be devoted to increasingly satisfying creative activities. Does this mean that everyone will become a computer programmer?

Not necessarily. But even if that were so, it would not be a wholly undesirable consequence, though we might have thought so a few years ago. The fact is that being able to "tell" computers what to do is becoming an increasingly valuable skill in our society. At the same time it is becoming easier and less the preserve of a privileged few. There are degrees, too, of programming expertise. Not everyone will want to design large-scale systems or to become systems analysts. But it is safe to say that most people will want to be able to do at least elementary things with computers: they will want to be able to run programs others may have written, and use the computer to communicate, to process information, and to retrieve data. In other words, they will want to be computer literate. Computer literacy is now a central issue in many educational circles and will become even more so as symbionic technology extends the need for this literacy.

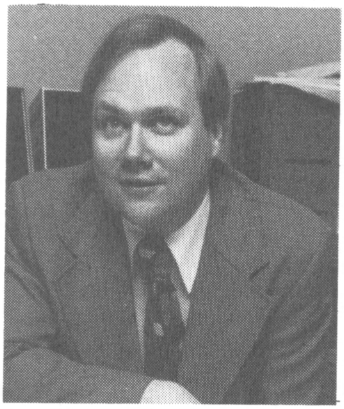
This paper began with a frightening quote about the future. Perhaps it would be wise to end with a more positive quote. Throughout, we have tried to examine current developments in a wide variety of areas from medicine and biotechnology, to computer science. The aim was to see if any trend was apparent. The intention was to see if a case could be made for the eventual merger of recent developments to create a super-technology. Indeed, the evidence suggests that it is rather unlikely that these areas will not merge at some time in the future.

It is not too difficult to forecast the types of technology that will emerge. It is much more difficult to examine their effects on society. Far from being a frightening scenario, the advantages of such a super-technology are far more likely to outweigh the disadvantages - if the effects on society are well understood, in advance. Though the symbionic age belongs to the future, our concern must be expressed in the present. We must give serious consideration now to the possible social, legal, ethical, and educational problems this new technology may bring. If we can begin this task now, then we are likely to make the best possible use of one of the richest potentials ever imagined. And maybe then the vision that Hald (1981, p. 58) sees of children of the future becoming geniuses relative to today's generation, will come to pass:

> I can see the children of the future bouncing through this playground of knowledge, motivated by curiosity and the fun of having their questions instantly answered, being assisted by either a human or computer guide, threading unique pathways through human knowledge. Imagine what it would be like, from birth, to be exposed to this type of media. A child would quickly become experienced searching for and finding information on anything, relating ideas and weaving patterns of understanding, developing a form of thinking that would be highly conceptual. By

today's standards, such a child would appear to be a genius. The impact on an entire generation could be dramatic. Our children's children may become the first genius generation.

(A condensed version of "The Impact of Symbionic Technology on Education," a paper prepared for the Research and Evaluation Branch, Ministry of Education, Government of Ontario, May 1982.)



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REFERENCES

Almy, M. C., Chittenden, E., and Miller, P. Young Children's Thinking. New York: Teachers College, Columbia University, 1966.

Angier, N. "The Organic Computer." Discover, May 1982, pp. 76-79.

"Artificial intelligence." Business Week, March 8, 1982. pp. 66-75.

"Biotech breathes life into microchips." Engineering Today. November, 1981, p. 11.

Bucke, R. M. Cosmic Consciousness: A Study in the Evolution of the Human Mind. Philadelphia: Innes & Sons, 1901.

Burke, B. "'Electronic hearing' draws mixed reviews." Journal of the American Medical Association. April 23/30, 1982. 247 (16): 2204-2205.

Butts, B. "Enzymes proposed as elements in tomorrow's 'genetic VLSI.'" Electronic Engineering Times. Monday, May 25, 1981.

Cartwright, Glenn F. "Symbionic minds: the advent of intelligence amplifiers." Paper presented at the First Global Conference on the Future, Toronto, July 1980a.

Cartwright, Glenn F. "And now for something completely different: symbionic minds." Technology Review, October 1980b. 83(1): 68; 70.

Cartwright, Glenn F. "Symbionic minds for the gifted." Invited paper presented at the Fourth World Conference on Gifted and Talented Children, Montreal, August 1981a.

Cartwright, Glenn F. "Toward a new level of awareness: symbionic consciousness." Invited paper presented at the annual meeting of the American Association for Social Psychiatry, New York City, October 1981b.

Cartwright, Glenn F. "Educational computing in the distant future." Paper presented at the Educational Computing Organization of Ontario (ECOO), Toronto, April 1982.

Chang, K. W., Aisenberg, S., Soeldner, J. S. and Hiebert, J. M. "Validation and bioengineering aspects of an implantable glucose sensor." Transactions of the American Society for Artificial Organs, 1973. 19: 352-360.

Check, W. "Brain stimulation for seizures, spasticity needs better evaluation." Journal of the American Medical Association. March 6, 1978. 239(10): 915-927.

Clarke, Arthur C. Childhood's End. New York: Harcourt, Brace & World, Inc., 1953.

Clarke, Arthur C. Profiles of the Future. New York: Harper & Row, 1973.

"Computerised movement for the paralysed." Journal of Medical

and Engineering Technology, May 1981. 5 (3): 109.
Cooper, I.S., Riklan, M., Amin, I., Waltz, J.M. and Cullinan, T. "Chronic cerebellar stimulation in cerebral palsy." Neurology, 1976. 26: 744-753
Craig, D. "GaAs chip may boost speed." Computing Canada, May 13, 1982. 8 (10): 9.
Dean, Stanley R. (Ed.) Psychiatry and Mysticism. Chicago: Nelson-Hall, 1975.
de Bono, Edward. Future Positive. New York: Penguin Books, 1980.
Delgado, José M. R. "Chronic implantation of intracerebral electrodes in animals." In Sheer, Daniel E. (Ed.) Electrical Stimulation of the Brain. Austin: University of Texas Press, 1961.
de Rosnay, J. "La biotique: vers l'ordinateur biologique?" L'Expansion, May 21, 1981.
"DHSS give go ahead to myoelectric hand." Journal of Medical and Engineering Technology, September 1981. 5 (5): 217.
Elliott, John. "Better artificial arms under development." Journal of the American Medical Association. June 13, 1980. 243 (22): 2277 and 2281.
EMV Associates. "Brain/computer direct link subject of NSF grant." Press release. Rockville, Maryland: November 1, 1981.
Englemann, S. Preventing failure in the elementary grades. Chicago: Science Research Associates, 1969.
Evans, C. The Micro Millennium. New York: Washington Square Press, 1979.
Fleisher, D. "Mind Machines." Science Digest, March 1982, p. 83.
"Futuristic computer biochips: new market for synthesized proteins." Genetic Technology News, October, 1981.
Ginsburg, H. and Opper, S. Piaget's Theory of Intellectual Development: An Introduction. Englewood cliffs, N J.: Prentice-Hall, 1969.
Gliedman, J. "Julian Jaynes and the ancient mindgods." Science Digest, April 1982. pp. 84-87; 114-115.
Golden, F. "Here come the microkids." Time, May 3, 1982, pp. 50-59.
Goldenberg, E. P. Special Technology for Special Children. Baltimore: University Park Press, 1979.
Gorney, R. "The human agenda: peril and survival." Journal of the American Academy of Psychoanalysis, 1981, 9(2): 185-209.
Hald, A. P. "Genius generation." In Watson, N. (Ed.) Microcomputing in education: getting started. Tempe, AZ: College of Education, Arizona State University, January 1981.
Heath, R. "Modulation of emotion with a brain pacemaker." Journal of Nervous and Mental Disease, 1977, 165(5): 300-317.
Hecht, J. "Lasers store a wealth of data." High Technology,

May/June, 1982. 2 (3): 60-67.
Hilts, P. "Odd man out." Omni, January 1981. 3 (4): 68-71; 87-88.
Hoover, T. "Intelligent Machines." Omni, October 1979. 2 (1): 60-64; 161-162.
Hunt, James McVicker. Intelligence and Experience. New York: Ronald, 1961.
Hunt, M. The Universe Within. New York: Simon and Schuster, 1981.
Hyde, J. E. The Phone Book. Chicago: Henry Regnery Co., 1976.
Jastrow, R. "The thinking computer." Science Digest, June 1982, pp. 54-55 and 106-107.
Jaynes, J. The Origin of Consciousness in the Breakdown of the Bicameral Mind. Toronto: University of Toronto Press, 1976.
"Just how small is a small memory chip?" The Montreal Gazette, March 30, 1982.
Kalnins, I. V., and Bruner, J. S. "The coordination of visual observation and instrumental behaviour in early infancy." Perception, 1973, 2: 307-314.
Kamii, C., and Dermon, L. "The Englemann approach to teaching logical thinking: findings from the administration of some Piagetian tasks." In Green, D. R., Ford, M. P., and Flamer, G. (eds.) Piaget and Measurement. New York: McGraw Hill, 1972.
Lowther, W. "An outlet for brainpower." Maclean's, June 30, 1980, p. 8.
Mason, R. and Jennings, L. "The computer home: will tomorrow's housing come alive?" The Futurist, February 1982. XVI, 1: 35-43.
McAlear, J.H. and Wehrung, J.M. "Biotechnical electron devices." NRL Workshop on Molecular Electronics, March 1981a.
McAlear, J.H. and Wehrung, J.M. Bioconductors - beyond VSLI." IEEE - Japan, App. Phys. Meeting. Maui, Hawaii, September 7-11, 1981b.
McAuliffe, K. "Biochip revolution." Omni, December, 1981, 4 (3): 52-58.
McLean, R. S. "Education toward computers as 'Intellectual Amplifiers.'" Toronto: Ontario Institute for Studies in Education, June 6, 1981a.
McLean, R. S. "The microcomputer has a role in human evolution." Toronto: Ontario Institute for Studies in Education, October 15, 1981b.
McLuhan, Marshall. Understanding Media: The Extensions of Man. New York: McGraw-Hill, 1965.
McLuhan, Marshall. "Living at the Speed of Light." Maclean's, January 7, 1980, pp. 32-33.
Mitchell, D. "The knowledge revolution." CAUT Bulletin, 29, 1, February 1982, pp. 15-16.
Myers, R.D. Drug and Chemical Stimulation of the Brain. New

York: Van Nostrand Reinhold Co., 1974
Papert, S. Mindstorms. New York: Basic Books, 1980.
Papert, S. and Solomon, C. "Twenty things to do with a computer." Educational Technology, April 1972, pp. 9-18.
Piaget, J. "How children form mathematical concepts." Scientific American, 1953. 189: 74-79.
Piaget, J. Science of Education and the Psychology of the Child. New York: Grossman, 1970.
Penfield, W. G. and Rasmussen, T. The Cerebral Cortex of Man: A Clinical Study of the Localization of Function. New York: Macmillan, 1950.
Pinneo, L. R., Johnson, P., Herron, J., and Rebert, C.S. "Feasibility study for design of a biocybernetic communication system." Menlo Park, California: Stanford Research Institute, August 1975.
Posa, J. G. Bioelectronics to spawn circuits. Electronics, September 8, 1981.
Restak, R. M. The Brain: The Last Frontier. New York: Doubleday and Company, 1979.
Renaud, Jacqueline. "Jose Delgado, l'homme qui est 'entre dans le cerveau'." Science et Vie. June, 1978. CXXIX (729), 24-33.
Selden, G. "Machines that read minds." Science Digest. October 1981. pp 60-63 and 112-114.
Sheer, Daniel E. (Ed.) Electrical Stimulation of the Brain. Austin: University of Texas Press, 1961.
Sheridan, T. "Computer control and human alienation." Technology Review, October 1980. 83 (1): 61-67; 71-73.
Simpson, C. "World Brain." Science Digest, May 1982, pp. 52-55; 93.
Siqueland, E. R., and De Lucia, C. A. "Visual reinforcement of non-nutritive sucking in human infants." Science, 1969. 165: 1144-1146.
Sperry, R. "Mind, brain, and humanist values." In Platt, John R. (Ed.) New Views on the Nature of Man. Chicago: University of Chicago Press, 1965.
Stein, K. "Brainstorms." Omni, October 1981. 4 (1): 52-58; 140-144.
Stine, Harry. "The Bionic Brain." Omni, July 1979, 1 (10): 84-86; 121-122.
Stockton, William. "Computers that think." New York Times Magazine. December 7 and 14, 1980.
Sweetnam, G. "The incredible shrinking microcircuit." Science Digest. January, 1982, pp. 80-81.
Takacs, Marianne. "How to smarten up." The Financial Post Magazine. March 1, 1982, pp. 67-72.
Taylor, G. R. The Natural History of the Mind. London: Secker and Warburg, 1979.
Telford, C. W., and Sawrey, J.M. The Exceptional Individual (third edition). Englewood Cliffs, N.J: Prentice-Hall, Inc., 1977.
"The next generation of microprocessors: molecular 'biochips'

instead of silicon wafers?" Biotechnology Newswatch, Monday, September 21, 1981, p. 7.
Toffler, Alvin. The Third Wave. New York: William Morrow and Company, 1980.
Ulmer, K. M. "Biological Assembly of molecular ultracircuits." Rockville, Maryland: Genex Corporation, n.d.
Vadgama, P. "Enzyme electrodes as practical biosensors." Journal of Medical Engineering and Technology, November 1981. 5 (6): 293-298.
Valenstein, E.S., Cox, V.C., and Kakolewski, J. W. "Re-examination of the role of the hypothalamus in motivation." Psychol. Rev. 1970. 77: 16-31.
Valenstein, Elliot S. Science-fiction fantasy and the brain. Psychology Today. July, 1978. pp. 29-31 and 37-39.
Vallee, J., Johansen, R., and Spangler, K. "The computer conference: an altered state of communication?" The Futurist, June 1975, 9: 3, 116-121.
"Whatever happened to molecular electronics?" IEEE Spectrum, December, 1981, p. 17.
Youcha, G. "Brain boosters." Science Digest, June 1982, p. 70.
Zimbardo, Philip G. "The age of indifference." Psychology Today, August 1980, pp. 71-76.
Ziporyn, T. "Evoked potential emerging as a valuable medical tool." Journal of the American Medical Association, September 18, 1981a. 246 (12): 1287-1291.
Ziporyn, T. "Evoked potentials give early warning of sensory and behavioral deficits in high-risk neonates." Journal of the American Medical Association. September 18, 1981b. 246 (12): 1288-1289.
Ziporyn, T. "Add EPs to list of intraoperative monitors." Journal of the American Medical Association. September 18, 1981c. 246 (12): 1291 and 1295.