DOCUMENT RESUME

ED 233 701 IR 010 792

AUTHOR	Cartwright, Glenn F.
TITLE	Symbionic Technology and Education. Report 83-02.
INSTITUTION	McGill Univ., Montreal (Quebec). Faculty of Education.
PUB DATE	Apr 83
NOTE	34p.; Paper presented at the Annual Meeting of the American Educational Research Association (Montreal, Canada, April 11-14, 1983).
PUB TYPE	Information Analyses (070) -- Viewpoints (120) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	*Artificial Intelligence; Bionics; Cognitive Processes; Communication (Thought Transfer); Computer Science; *Cybernetics; Electronic Control; Futures (of Society); Instructional Innovation; *Man Machine Systems; *Technological Advancement; Technology Transfer
IDENTIFIERS	Biocybernetics; *Biotechnology; Brain Research; Electromyography; Interface System; Microelectronics

ABSTRACT

Research findings indicate that major breakthroughs in education will have to occur through direct cortical intervention, using either chemical or electronic means. It will eventually be possible to build sophisticated intelligence amplifiers that will be internal extensions of our brains, significantly more powerful than present day computers, which may even be directly wired to the brain for both input and output. Development of such symbionic (symbiotic + bionic) devices can be projected based on emerging research in five areas: (1) "emgors" (electromyogram sensors) for controlling artificial limbs; (2) brain pacemakers and electrical brain stimulation; (3) biocybernetic communication and neurometrics, including the link between brain wave patterns and specific thoughts; (4) artificial intelligence; and (5) biocybernetics, including the use of genetic engineering principles to construct tiny biological microprocessors or "biochips." A merger of these steadily-converging areas could allow creation of the symbionic mind, defined as any apparatus consisting of some useful device interfaced with the human brain, which is capable of intelligent action. The current growth of microcomputers foreshadows a trend towards a change in the way learning occurs which symbionic technology will extend, changing the role of the student, teacher, school, and individual in society. This report lists 75 references. (LMM)

ED233701

SYMBIONIC TECHNOLOGY AND EDUCATION

Glenn F. Cartwright

Computer-Based Instructional Research Lab (CBIRL)
Department of Educational Psychology and Counselling
and
Centre for Teaching and Learning Services

McGill University

A paper presented at the Annual Meeting of the
American Educational Research Association
Montreal, Quebec

IR010792

April, 1983

Report 83-02

ABSTRACT

After many years of research, it is becoming apparent that major changes in education are not going to be brought about by minor improvements in instructional design nor by enhancements to conventional educational technology. Indeed, if a major breakthrough is to occur at all, the evidence suggests that it will have to be brought about by direct cortical intervention using either chemical or electronic means. This paper explores the latter and describes the possibilities particularly with respect to biochip technology and the impact that may have on education and educational practice in the future.

Note

For an expanded version of this paper, see Cartwright 1982b and 1983.

SYMBIONIC TECHNOLOGY AND EDUCATION

> **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.**
>
> **(Hald, 1981, p.58)**

Traditional approaches to improving instruction have often centered on the nature of the instruction itself. Most attempts have concentrated on improving either its design or its delivery. But decades of research in both areas consistently demonstrates that changes to design or delivery systems, while improving performance somewhat, fail to bring about significant change of the magnitude that might be considered a breakthrough. It may very well be that we have reached the limit of conventional instructional improvement, and that some new approach must be found if optimal enhancement is to occur. Naturally, this is a difficult position for most instructional designers to accept, especially those who have dedicated their lives to improving instruction by conventional means. Nevertheless, the possibility that learning may be enhanced in the future by some wholly new means must be considered.

To date, little attention has been paid, at the physiological level, to improving the learners' ability to learn. This is partly because educators are not equipped to undertake such a task, and partly because it is not known at present how such enhancement might be accomplished.

This situation is likely to remain. But advances are occuring in both the biochemical and electronic enhancement of the human brain. Though educators will not bring about these changes, they will have to be aware of these developments so that they may adjust the current educational system, including curricula, to future needs.

This paper contends that if future breakthroughs are to occur in the area of learning, they will be brought about chiefly through biochemical (Hansl & Hansl, 1979) and/or electrical enhancement. This paper deals with the latter as an example of a scenario which could have profound changes in education.

Intelligence Amplifiers

Computers and calculators already amplify our intelligence in a limited way (McLean, 1981a), and 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. There are still a number of interfaces like keyboards, line printers, and video screens 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), 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; Cartwright, 1982a). 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.

Connections

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.

1. Emgors

The first of these is the recent appearance of "emgors" (electromyogram sensors) 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," 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 for children three-and-a-half to four-and-a-half years old, which 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 demonstrates 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 behaviors showed little consistency and often behaviors 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 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. 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 behavior. 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 behavior. 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 like 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 (Youcha, 1982). 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, 1981). 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 <u>any device which now exists would be intrinsically more useful were it under the direct control of the human brain</u>. 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. 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).

As 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 silicon 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). For example, the Nippon Telegraph and Telephone has already developed a 1-million bit chip of gallium arsenide that operates twice as fast as other memory chips while consuming far less power. Successful though the silicon chip is today, new protein 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 due 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; Yanchinski, 1982). 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 Handwriting 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 indirectly by picking up brain waves with external sensors, or directly by using electrodes implanted or grown-in-place, 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.

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?"

Functions of the Symbionic 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.

It is easy to see how people with failing memories might benefit from 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. 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, it might be possible to have the symbionic mind receive television pictures directly without the aid of a TV receiver, channeling them through the symbionic mind directly to the brain. One would still have the sensation of "seeing" the pictures yet one's 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. For example, Dr. William F. House at the Otologic Medical Group Inc., in Los Angeles uses a technique to implant <u>a single electrode</u> in deaf patients; in San Francisco at the University of California, clinical professor of otolaryngology Dr. Robin P. Michelson implants single units of <u>eight electrodes</u>; and at the University of Paris medical school, Dr.

Claude-Henri Chouard has developed a method of implanting twelve electrodes.

The immediate goal of this type of research is to develop an artificial ear. Such a device might be of some help to the estimated 300,000 Americans who now suffer profound hearing loss and who are considered beyond the help of surgery or hearing aids. But whatever the obvious medical advantages to the deaf, the end result is that this kind of research represents the beginning of the creation of a direct interface with the brain, and perhaps even the eventual development of artificial senses of use to everyone.

If it were possible to build such artificial senses and connect them directly to the brain, then it may also be possible to build totally new senses and wire them in as well. Some of these might include components of our existing five senses; others will be totally new and the line distinguishing one sense from another may become increasingly blurred. Exactly what these new senses will be and the uses to which we shall put them must remain, for the moment, in the realm of speculation, but one example might be a totally new sense to detect currently invisible hazards like harmful levels of radiation or other kinds of pollution in our immediate environment.

The creation of such devices, while difficult, may not be insurmountable. For many years it was believed that the human cortex was simply too complex to simulate. Recent attempts, however, to develop computer simulations of the cerebellar cortex of the frog have produced interesting results. Certain functions seemed to be independent of how the cells were connected. This led the authors to conclude that the spatial distribution of the circuits may, under certain circumstances, be more important than specific connections at the single cell level (Pellionisz & Llinas, 1977; Pellionisz, Llinas & Perkel, 1977). What this may mean for the creation of brain prostheses is that it may not be necessary to duplicate the exact wiring of parts of the cortex. The sheer mass of cells may produce the required functions without reliance on specific wiring connections.

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. 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 our fast-moving world. 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.

It 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.

Symbionic Synergy

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. 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.

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 behavioral 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 favor 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 [illegible] infants just a few weeks old could focus pictures by sucking on [illegible]nmy 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.

Teaching Behavior

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, 1982a). 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. In fact, 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, 1982a).

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.

Throughout this paper, 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 likely that these areas will 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. If we can begin this task now, then we are more likely to make the best possible use of one of the richest potentials ever imagined. And maybe then Hald's vision, quoted at the beginning of this paper, of future children becoming geniuses relative to today's generation, will finally come to pass.

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.

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. 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 1981.

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

Cartwright, Glenn F. The impact of symbionic technology on education. Paper prepared for the Department of Education, Government of Ontario, May 1982b.

Cartwright, Glenn F. The symbionic mind. McGill Journal of Education, Winter, 1983. 18 (1): 5-37.

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.

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.

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.

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.

Golden, F. Here come the microkids. Time, May 3, 1982, pp. 50-59.

Hald, A.P. Genius generation. In Watson, N. (Ed.) Microcomputing in education: getting started. Tempe, AZ: College of Education, Arizona State University, January 1981.

Hansl, N., and Hansl, A. Learning and memory improvement through chemistry: dream or reality in the offing? Phi Delta Kappan, 1979, 61 (4): 264-265.

Heath, R. Modulation of emotion with a brain pacemaker. Journal of Nervous and Mental Disease, 1977, 165(5): 300-317.

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.

Jastrow, R. The thinking computer. Science Digest, June 1982, pp. 54-55 and 106-107.

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 behavior 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.

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.

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.

Pellionisz, A., and Llinas, R. A computer model of cerebellar purkinje cells. Neuroscience, 1977, 2, 37-48.

Pellionisz, A., Llinas, R. and Perkel, D. A Computer Model of the Cerebellar Cortex of the Frog. Neuroscience, 1977, 2, 19-35.

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.

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.

Siqueland, E. R., and De Lucia, C. A. Visual reinforcement of non-nutritive sucking in human infants. Science, 1969. 165: 1144-1146.

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.

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. Reexamination 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.

Whatever happened to molecular electronics? IEEE Spectrum, December, 1981, p. 17.

Yanchinski, S. And now - the biochip. New Scientist, January 14, 1982. pp. 68-71.

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.