Expanding the Range, Dividing the Task: Educating the Human Brain in an Electronic Society

We need to create curriculums based on the complementary relationship between the human mind and the machines we develop to supplement our capabilities.

Recent developments in both brain research and computer technology pose complex curricular issues. We are currently laboring hard to teach students many skills that small, readily available calculators and computers can process more efficiently and effectively. Rather than continue this traditional practice, we should base our curriculum decisions on an understanding of the brain's capabilities, limitations, and interests.

New technologies have always emerged out of the limitations and interests of the brain's sensory/motor and problem-solving mechanisms—narrowing the distance between what we can do and what we would like to do. Typewriters, telescopes, telephone books, and trigonometry are but four of the rich complex of technologies that we have developed to expand the brain's ability to gather/process/interpret/use information. Schools, though, lag far behind society in adopting new information technologies. For example, the typewriter has existed for well over a century, the word processor for about a quarter of a century. Although they've transformed written communication in our society, we've provided K-12 classrooms with few of them.

This article provides background information on five properties of the brain that are central to the issues of how best to divide educational tasks between minds and machines and how to create curriculums that will help students understand the complementary relationship between the brain and the supportive machines that human brains develop. I will argue that the curriculum should focus principally on knowledge/skills/values that (1) most characterize and enhance our brain's capabilities and (2) teach students how best to use appropriate technologies on tasks that characterize the brain's limitations.

To succinctly state the differences, the human brain is currently much better than computers at conceptualizing ambiguous problems—at identifying definitive and value-laden elements that it can incorporate into an acceptable general solution. Conversely, computers are much better at rapidly, accurately, and effectively processing complex se-

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A curriculum that makes use of calculators for boring, repetitive work increases the amount of time students can spend involved in tasks that are more stimulating and challenging.

quences of clearly defined facts and processes that would otherwise require a high level of sustained mental attention and precision.

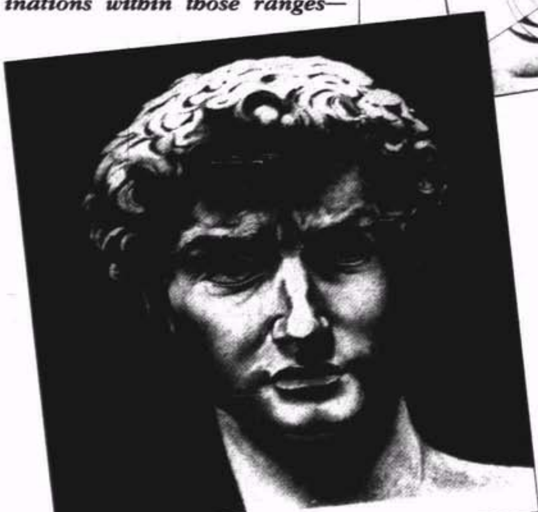
Or to state it in classroom terms, teaching is generally a delightful experience when we focus on activities that student brains enjoy doing, and do well—such as exploring concepts, creating metaphors, estimating and predicting, cooperating on group tasks, and discussing moral/ethical issues. Conversely, teaching loses much of its luster when we force students to do things their brains don't enjoy doing, and do poorly—such as reading textbooks that compress content, writing and rewriting reports, completing repetitive worksheets, and memorizing facts they consider irrelevant. Now let's examine five key capabilities and limitations of the brain and the computer.

Rigid sensory/motor controls underscore human brain activity. They limit input and output to narrow ranges; and they limit our ability to make fine discriminations within those ranges—but our curiosity has led us to vigorously explore the universe beyond those limitations.

Sensory limitations/expansions. The information that our brains' specialized sensory receptors receive from the surrounding environment is somewhat meaningless initially—variations in temperature, touch, and air pressure, reflected light rays, and the chemical composition of air/water/food. Further, our sense organs function within relatively narrow ranges (e.g., 10 octaves of sound, about 30 odor-producing molecules, the narrow band of visible light in the broad electromagnetic spectrum).

It doesn't seem like much, but those variations are the source of all the external information that our brains transform into cognitive representations of the world. An exceptional sense of taste and smell can provide a wine taster with a vocation, and psychedelic drugs can briefly expand our sensory range—but we normally function within a narrow, genetically determined sensory range.

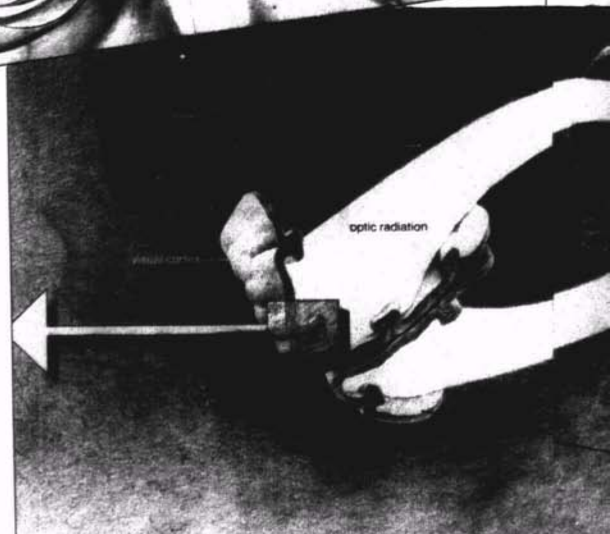
It makes sense. Our brains couldn't possibly process all the information that the surrounding molecules and vibrations carry. However, we've always been curious about what exists beyond our sensory range, and so we've developed such technological



A Young Man Recognizes His Mother

or

A simplified tour of the visual system



One optic nerve passes through the rear of each eyeball, meeting shortly thereafter at the optic chiasm. Here, about half the fibers from each eye cross over to the opposite side of the brain while the other half continue on the same side. The two rearranged bundles of fibers leaving the optic chiasm are called optic tracts, and they deliver the message to an area of each thalamus called the lateral geniculate body. Although each electrical impulse registers in a particular layer of the lateral geniculate body, the complete message remains unchanged and continues on through two large sets of fibers, called the optic radiation, to the occipital lobe, or visual cortex, of each hemisphere for analysis.

extensions as microscopes and telescopes, and oscilloscopes that transduce unhearable sounds into visible patterns.

Computers have materially broadened our knowledge of the universe by expanding the range and precision of such sensory technology. The curriculum should help students understand and master this technology, but it should also examine the social value of information that exists beyond the brain's limitations. For example, a computerized camera can now identify the winner in a race by differences of hundredths of a second, when our visual systems and less precise brains would have called it a dead heat. The curriculum should encourage students to ask: How important is such expensive accuracy to the human spirit, when a race is but a game? Does precise information become important to an imprecise brain simply because it's technologically available?

Motor limitations/expansions. Conscious and unconscious brain mechanisms operate our jointed motor systems. This system is similarly limited in its range/speed/strength, but it can directly and technologically send information far beyond our immediate body ranges.

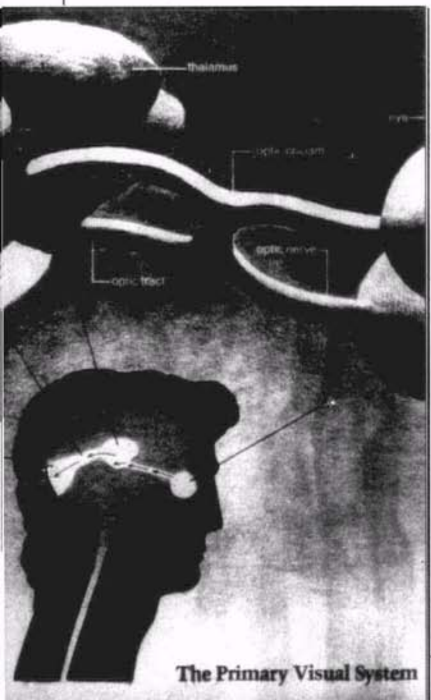
We've long engaged in competitions to discover the limits of our own movement capabilities. Some people devote their youth to such goals as trying to jump a fraction of an inch higher than anyone else. Further, mechanical and computerized technologies, such as cars and telephones, that materially increase the range and speed of human movement and communication seem almost to define our current culture and economy.

Our brain's motor system drives the communication skills that dominate the curriculum. Relatively complex brain mechanisms and muscle groups control the mouth and hand movements we use in interpersonal communication. Our voices are directed to hearing, and hand/finger movements primarily to vision (generally via paper). Both muscle groups are most efficient when they function automatically—when the conscious brain can focus on the content of the message rather than on the vehicle of expression.

Thus, we have long taught cursive writing because its automatic flowing nature permits writing speeds between 15–30 words a minute. But with much less instructional time, elementary students can learn to touch-type well beyond that speed, and in the years ahead, word processors with spelling checkers and superb editing capabilities will be readily available for any extended writing students will do.

This information suggests that we should phase out cursive writing as our principal technique for extended automatic writing. Rather, we should teach elementary students to compose stories/reports/letters directly on word processors and to use manuscript or cursive writing primarily for shorter notes and forms. Composing on a keyboard, like writing with a pencil, is an acquired skill. Its speed and rhythm are often more tuned to the speed of our thought processes than is cursive writing. Indeed, writing composed directly on a word processor tends to become conversational in style.

Developments in oral communication technologies further complicate this issue. In our increasingly oral society, one could ask how important it is to write fast when the telephone is



The Primary Visual System

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See also p. 79

MAMA!

This greatly simplified tour of an incredibly complex ... events has taken at least several thousand times ... than the fraction of a second in which the actual ...

Free Play: Improvisation in Life and Art

Stephen Nachmanovitch
Los Angeles, Calif.:
Jeremy P. Tarcher, Inc.

Conventional wisdom says there is a time for work and a time for play. In *Free Play: Improvisation in Life and Art*, Stephen Nachmanovitch draws on Zen Buddhism to make a convincing case for disposing of this artificial dichotomy in favor of play—in the widest sense—in all aspects of life: Play is "not what we do, but how we do it." Written for people who want to achieve their full potential as well as awaken creativity in others, the book explores how the free play of consciousness can be the master key to inspiration, motivation, and fulfillment. Nachmanovitch, a musician and teacher, calls on educators to liberate students' creative voices by improvising and being faithful to the moment, rather than simply following a script. By approaching teaching and learning as artists, teachers and students will find that work and play become one—creative and intrinsically rewarding. Illustrated with artwork from both Eastern and Western traditions.

Available in hardback for $16.95 from Jeremy P. Tarcher, Inc., 5858 Wilshire Blvd., Suite 200, Los Angeles, CA 90036.

—Reviewed by Lars Kongshem

even faster. Further, voice input/output capability in computers is also developing rapidly. Its advent will be a curricular boon for handicapped students, but it will also create curricular adjustments for those with normal proficiency in language. For example, clear diction and correct syntax will become more important when we speak into computers that require them than when we talk to people, whose brains can easily adapt to errors in speech and syntax.

Our brain can quickly identify potentially important incoming information—separating foreground from background information—and it can briefly hold elements of the foreground information in its short-term memory.

The brain is designed to merely monitor most of the low contrast sensory information that flows into it (e.g., blank walls/single tones), but it automatically attends to high contrast information (e.g., lines, edges, movement, oscillating sounds, a blast of cold air). For example, your brain is currently aware of the paper that constitutes this page (background), but it focuses its attention on the high-contrast lines that make up these words (foreground). Long before brain researchers discovered that the information in lines is sent into the brain with more strength than the information in solid areas, we humans had exploited this property by creating written languages that used combinations of lines on paper to represent words.

This initial automatic separation of foreground from background at the point of contrast certainly simplifies the critically important analysis task that follows within our brains. Our limited short-term memory buffer can briefly hold potentially important information from the current sensory field while we decide whether to attend to it further and/or store it in long-term memory. But we must decide quickly because the continual influx of new information will delete anything not consciously held.

Since short-term memory space is limited to perhaps a half dozen units of information at any one time, we must rapidly combine related bits of foreground information into single units by identifying similarities, differences, and patterns that can simplify and consolidate an otherwise confusing sensory field. The need to respond quickly has enhanced our ability and willingness to estimate, certainly one of our brain's major strengths.

Our conscious brain thus monitors the total sensory field while it simultaneously searches for and focuses on familiar/interesting/important elements—separating foreground from background. Even an infant can easily outperform an advanced computer in quickly recognizing its parents in a group of people. Extensive experience in a field develops these rapid editing skills to the expert level. Thus, the curriculum enhances this remarkable brain capability when it focuses on the development of classification and language skills that force students to quickly identify the most important elements in a larger unit of information.

The strong appeal of computerized video games may well lie in their lack of explicit directions to the players, who suddenly find themselves in complex electronic environments that challenge them to quickly identify and act on the important elements. Failure sends the player back to the beginning, and success brings a more complex (albeit attractive) challenge in the next electronic environment.

I watch in amazement as my 5-year-old grandson zips through the complexities of the electronic world that the Super Mario Brothers inhabit, and I wonder how eagerly he'll respond to the paper worksheets he'll shortly confront in kindergarten. Their directions will be clearly stated; their information will be static and uncomplicated; and, alas, their level of mental stimulation will generally be much lower.

We can't always mentally keep up with the rapid flow of information. Class notes and tape recorders testify to the limitations of our short-term memories to delay and hold the flow of complex experiences. Good class notes are active and selective and thus enhance the development of critically important rapid synthesizing skills. Conversely, a tape recorder passively stores everything the microphone picks up, and so it can reduce the stimulating mental pressure the listener would otherwise feel during the presentation to identify and write down the important elements immediately (without the security of instant replay via tape recorder).

Students need many opportunities to develop their short-term memory capabilities through experiences such

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as debates and games that require them to rapidly analyze complex information and briefly hold it. When textbooks and teachers highlight all the important information and software is too user-friendly, learning becomes more efficient, perhaps, but students also experience a reduction in the necessary challenge and enjoyment they get from continuously separating foreground information from background.

Our brains have a limited interest and attention span. We tend to focus on novel and intense information because of their strong contrast and emotional content, and we are stimulated by the successful completion of challenging tasks. Thus, the lack of contrast in routine and repetitive tasks bores us, and we do them inefficiently and ineffectively.

We have turned many of these tasks into low-paying service jobs and/or developed computerized machines to do them for us—and we can expect this trend to continue. For example, supermarket checkers who formerly responded mentally and rapidly to a cart full of groceries now merely run the items across a visual scanner. Many fast-food checkers now use cash registers that have replaced numbers with pictures of hamburgers/french fries/soft drinks on programmed price keys. Telephone operators who used to talk to the people who needed their help now activate voice synthesizers that provide computerized responses to common questions.

The long-term curricular and occupational implications of this development in computer technology will be disquieting unless we develop alternate challenging activities that enhance the estimating and pattern-recognizing skills that contribute heavily to an effective short-term memory.

Our brains can store potentially useful information at multiple levels of long-term memory representation that successively reduce the role of emotion, context, and the conscious regulation of recall.

When important and potentially recurring events occur, our brains may develop representations of the object or experience within long-term memory assemblies, which are specialized networks of neurons that our brains alter to function as a unit during recognition or recall.

It's possible that sleep and relaxation enhance the physical altering of these synaptic connections, since they are periods of less potential interference from sensory/motor and problem-solving activity (think of detours during road repair). Some powerful emotion-laden memories develop almost immediately after a single event, while other (often less effective) memories may require much effort over many trials.

Since a memory is a neural representation of an object and/or event, it is often tied to the context in which it occurred, and emotionally important contexts create powerful memories. Objects and events that registered in several sensory modalities can be stored in several interrelated memory assemblies, and such memories become more accessible and powerful, since each sensory memory checks and extends the others.

Recognition is easier than recall, since recognition often occurs in the original (or a similar) context of the memory. If the emotional setting in which a memory originally occurred is tied to the memory, recreating the original emotional setting enhances the recall of the memory and related memories (e.g., family arguments tend to spark memories of prior related disagreements). Thus, emotional multi-sensory school activities such as games/role playing/simulations/arts experiences can create powerful memories.

Our brains process several interrelated types of memory systems. For example, *declarative long-term memories* are factual label-and-location memories—knowing the name of my computer, where it's located. They define named categories, and so are verbal/conscious. *Episodic* declarative memories are very personal—intimately tied to a specific episode or context (my first attempt to run my computer, my joy at discovering how it simplified writing). *Semantic* declarative memories are more abstract—symbolic and context-free. They can be used in many different settings and so are important in teaching for transfer (knowing how to use function keys and software). My semantic understanding of the typewriter and its keyboard simplified my moves from manual typewriter to electric typewriter to word processor.

Initial skill learning, such as learning to type, is often episodic—the memories contain both foreground and background elements of the experience. When I learned to type, my teacher/classroom/typewriter provided an important, easily remembered emotional context during the initial learning period. It would have been inefficient for me to continue to recall all of these background elements whenever I typed, however, and so my teacher used class/home drills and different typewriters to help me eliminate the context of the learning (background) from the execution of the skill (foreground).

My typing knowledge and skill had thus become semantic—more abstract, but also more useful in a wide variety of keyboard settings and tasks (background). In effect, my brain erased the background information from my memory by reducing its frequency and significance, and thus strengthened the foreground information by focusing on it.

My typing speed was limited, however, by my continued simultaneous conscious spelling of words and activation of keys, and so I also had to eliminate this conscious behavior through a transfer of skills from semantic declarative memory to procedural memory—to master automatic touch typing.

Procedural long-term memories are automatic skill sequences—knowing how to touch type. They do not rely on conscious verbal recall (except to initiate/monitor/stop the extended movement sequence), and so they are fast and efficient. They are difficult to master and to forget. They are best developed through observation of experts, frequent practice, and continual feedback. As a skill develops, the number of actions processed as a single behavioral unit increases, and prerequisite skills are integrated into advanced skills.

Thus, when I was learning to type, I knew where all the keys were, and I was slow. Today, I don't consciously know where any of the keys are, and I'm a fast, efficient typist. My fingers have now become an automatic extension of my brain's language mechanisms.

Our brain is most efficient at recalling and using episodic memories that have important personal meanings. It is much less efficient at mastering the important context-free semantic and procedural memories. That's why the curriculum has to spend so much time/energy on worksheet-type facts and skills that are isolated from specific contexts. Conversely, computers, reference books, and so on are very reliable with facts and procedures, but they lack the emotional contexts that make our value-laden episodic memories so rich.

This knowledge suggests that we should teach students how to solve problems by combining their brains' subjective episodic strengths and emotional integrity with the objective semantic and procedural strengths of the new information technologies. For example, my decision to develop this article evolved principally out of the rich context of my personal studies and experiences, but my writing of the article also drew heavily on the university library, my own reference library, my ability to select the ideas that best fit the focus of the article and to write them clearly, and on the superior letter-formation and technical editing capabilities of my word processor/printer.

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Students should not be overwhelmed by the power of computerized machines simply because the machines are fast and efficient. They need to realize that being able to do something efficiently isn't the same as knowing whether or not it should be done. Our generation has tended to reduce the discussion of the importance of a problem when we've developed an efficient technical solution to it. The curriculum must help the next generation to move beyond that tendency.

Our brains can solve problems at multiple decision points, but we seem oriented toward making early decisions with limited information.

The brain's problem-solving mechanisms appear to be located principally in the large frontal lobes, the part of the brain that matures last. We have more frontal lobe capacity than we normally need to survive, because our brain's problem-solving mechanisms must be sufficient for crisis conditions (just as furnaces must be able to function effectively on the coldest day of the year).

Since our survival doesn't require our problem-solving mechanisms to operate at capacity most of the time, we've invented social and cultural problems to keep them continually stimulated and alert. Games, the arts, and social organizations provide pleasant metaphoric settings that help to develop and maintain our brain's problem-solving mechanisms. They are not trivial activities, in life or in the curriculum. Jean Piaget's suggestion that play is the serious business of childhood attests to the important developmental and maintenance roles that such activities play in problem solving.

Our brain can rapidly process ambiguities/metaphors/abstractions/patterns/changes. It can quickly categorize 100 leaves as maple leaves even though no two of the leaves are identical, and it can recognize a classmate at a 25th reunion despite all the changes that have occurred. This capacity permits us to succeed in a world in which most of the problems we confront require a quick general response rather than detailed accuracy. Thus, we quickly classify objects into general categories and estimate general solutions to our problems. We then adapt our preliminary decisions to any new information we might gather and use reference materials and machines to achieve further levels of precision, if they are necessary.

Our brains are better, therefore, at discovering conceptual relationships than at processing the accurate details that computers handle so well. We call it intuition, common sense—and we depend on it for much of what we do. It can lead to mistakes and to the overgeneralizations of stereotyping and prejudicial behavior—and also to music, art, drama, invention and a host of other human experiences that open us to the broad exploration of our complex world.

Language itself evolved out of these capabilities/limitations. It's a response to our need to develop a simple sequential coding system that can rapidly represent a complex information system and thus simplify problem solving and the need to communicate that often accompanies it. Our language uses only about 50 sounds and 50 visual symbols (letters/punctuation marks/digits/math symbols) to create its vocabulary of half a million words. It does this by coding meaning into precise letter sequences and word lengths (do/dog/god/good) and not into the 100 sounds and symbols themselves. Verbal language is thus similar to our genetic language, whose DNA coding system also uses sequence and length to assemble combinations of 20 different amino acids into the vast number of protein molecules that join to form a living organism—a solved problem.

Thus, our imprecise brains have adapted the basic structure of an existing internal genetic code into a precise external verbal code (although Mark Twain once suggested that only an uncreative person can think of only one way to spell a word). Our language has become so complex because we continually add words all across the general-to-precise continuum—from the general term *car* to the more precise *sports coupe*, from *man* to *Robert Alfred Sylwester*.

We can anticipate that computer technology will further expand the basic properties of genetic/verbal languages into new forms of technological language. The curriculum should therefore expand from its current focus on merely teaching students how to use language correctly to a broader extent that also teaches them the fundamental nature of information and language.

The rapid development of precise computerized information suggests another change in curricular focus. We should concentrate more on developing students' ability to quickly locate/estimate/organize/interpret information, and we should teach them how to use the superior speed and accuracy of available information technologies whenever a complex problem requires an accurate solution. Hypercards, spread sheets, statistical programs, and spelling checkers are only a few examples of the rapidly developing software literature that can assist our imprecise brains to solve problems and communicate ideas with detailed accuracy.

Because these software programs eliminate problem-solving steps we formerly did mentally, we have a legitimate concern that students who learn how to solve a class of problems via such software won't understand important steps in the solution. It isn't enough to suggest that many people who drive cars don't understand the internal combustion engine. We must develop curriculums that effectively explain the complete solution process while teaching the student how to use a computer to solve the problem.

Most of the brain's development is adapted to the challenges of the environment in which we live, and a stimulating environment that includes much social interaction enhances this development.

The brain's principal activity is to change itself. Early brain development focuses on the stable, preprogrammed, automatic mechanisms and processes that are dedicated to biological survival and to the smooth operation of the body and its movements (circulation/respiration/walking).

Childhood and adolescent development focus on environmentally dependent and adaptable neural networks that are dedicated to the learned exploration of the inner self and the external environment (language/memory/problem/solving/ socialization skills). Most children are born capable of easily mastering any of the world's 3,000 languages, and American children must learn an average of almost a dozen new words a day to reach the normal vocabulary of a high school graduate.

A stimulating social environment enhances this later development, since our brains develop and alter many of their mechanisms in response to environmental challenges. Children reared or educated in a limited and boring environment will not develop the efficient broad-based brain mechanisms they'll need for effective behavior within a complex social environment. Interactions with other people seem to stimulate us more than anything else—and we have a marvelous capacity for love and commitment to one another.

Our mass culture cries out for cooperative learning and doing. Computers always function within human information networks, and so they can enhance or diminish our potential for cooperative behavior. Teachers can enhance this potential by asking students to collaborate on activities that incorporate computers, by discussing social issues that emerge out of computer use, and by emphasizing human values when information is processed electronically.

An interesting development has emerged in the schools' use of word processors. When students use a paper and pencil or a typewriter, classroom writing is essentially a solitary act because the writing can't be easily read by anyone other than the writer. With their upright brightly lit screens, word processors make writing more of a public act in a classroom. That other students read/discuss/edit the text can enhance the collaborative activities that add context to acquired knowledge.

What is an appropriate stimulating environment for the developing brain of a contemporary child? Electronic information technologies can now create high-resolution graphic representations of real and imaginary worlds far beyond traditional verbal and visual representations, but they distort time, space, and reality in the process. Still, such things as instant replay, special effects, and computer joy sticks have become such an integral distortion of the real world that they are probably a necessary element in the education of students—whether we like it or not.

Our Curricular and Staff Development Challenges

We won't return to an earlier simpler world in which our brains had to do almost everything within themselves—with the sometime assistance of information stored in the increasingly complex and cumbersome print-oriented collection our society had amassed. We've now developed a class of powerful portable electronic machines that rapidly do the things our brains don't want to do—and don't do well. These technologies move our brain well beyond its normal range/speed/power. In doing so, they create a new set of problems about the value of the gain in relation to the effort and cost that our schools haven't faced before. Are things worth doing simply because we can do them?

Stress- and drug-related illnesses are part of the personal and social costs of educational and technological efforts to force our brains to function well beyond their normal capabilities—whether that be to require students to use paper and pencil to solve math problems they don't understand and consider irrelevant or to use an equally incomprehensible computer program.

Our profession must seriously examine the dramatic developments in cognitive science and computer technology. Doing so will enable us to identify and redesign the obsolete elements of our generation's version of The Saber-Tooth Curriculum, which, because it had evolved into such an effective curriculum, continued to teach tiger-killing skills after all the tigers had been killed.[1]

This article has suggested a general approach—and explored it through five brain capabilities/limitations that relate to emerging curricular issues. Use this general introduction to focus your own thinking and to initiate discussions with colleagues that focus on your specific professional assignments. If our profession is going to move toward broadly accepted curricular policies and practices, however, we must engage in vigorous study that will move a critical mass of educators to a reasonable understanding of educationally significant developments in the cognitive sciences and to a hands-on understanding of new developments in computer technology. Join that critical mass.☐

[1]H. Benjamin, (1939), *The Saber-Tooth Curriculum* (New York: McGraw-Hill).

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