New knowledge about functioning of the human brain may enable schools to teach thinking more effectively. We asked four authorities to list:

Educational Implications of Recent Brain Research

Photo: Michael Sexton

ROBERT SYLWESTER

The brain is the most magnificent three pounds of matter in the universe. What we now know about the human brain and what we'll discover in the years ahead may well transform formal education.

Unfortunately, the present social science/behavioral orientation of our profession creates a problem. Education majors tend to shy away from biology and chemistry courses, and most practicing educators don't read brain research. Further, brain researchers typically don't focus on education implications or publish in education journals. The result is an education profession largely unaware of significant brain research, ripe for blind acceptance of generalizations and fads.

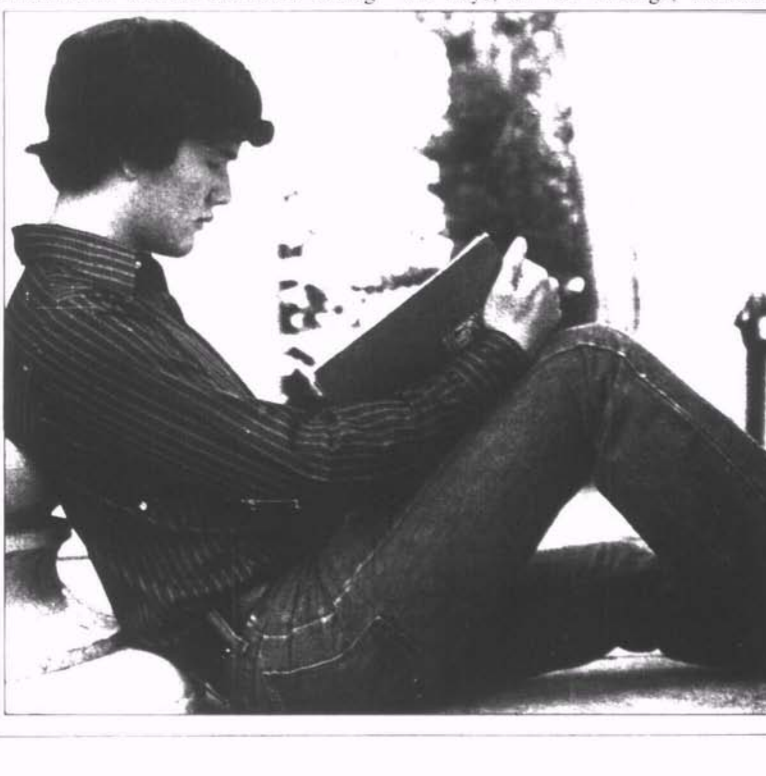
Educational change generally takes a generation or longer as new information is disseminated across the profession. Will parents allow us that much time if new brain discoveries clearly show that educational adaptations will affect the quality of their children's education?

Let's consider one example. The final pound oι the adult three-pound brain develops between the ages of 2 and 16. This growth involves the development of more remote axon/dendrite extensions throughout the neural network, and the formation of an insulating layer (myelin) around axons. This final pound of growth enhances the brain's efficiency and capability. Epstein[1] has discovered that this growth does not occur continuously, but rather in sequences of (1) short periods of rapid growth that create the neural networks needed for new cognitive functions, such as speaking and reading; and (2) longer periods of practically no growth when the new functions are probably integrated into the total cognitive system. This sequence of growth and dormancy occurs frequently in nature (for instance, tree growth).

Three periods of brain growth occur during the school years. Most normal children experience a rapid 5 to 10 percent brain weight increase between the ages of 2-4, 6-8, 10-12+, and 14-16+. In normal children this growth spurt occurs during a period of about six months sometime during the two-year period, generally earlier for girls and later for boys. During the 10-12+ growth spurt, female brain growth is about three times that of males, and the situation is reversed, favoring males, during the 14-16+ brain growth period.

Epstein reports other discoveries, but for now it's probably enough just to consider the educational implications of these three statements:

1. Brain growth occurs during six of the 12 school grades. About every ten days, on the average, someone



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"Brain growth occurs during six of the 12 school grades. About every ten days, on the average, someone in each classroom begins or ends a brain growth spurt."

in each classroom begins or ends a brain growth spurt.

2. About one-fourth of the students will go through a growth spurt during the summer when schools are closed.

3. Significant normative sex differences exist in brain growth patterns.

What do these discoveries imply for individualization, year-round schools, grade acceleration/failure policies, and homogeneous classrooms?

It's still too early for schools to effect immediate organizational, curricular, and instructional changes. For example, we don't yet know how to determine when a given child's brain growth is beginning and ending, nor do we have the complete picture of where growth occurs in the brain, nor are we certain of the appropriate instructional strategies for growth and plateau periods.

Other areas of brain research also have much educational significance—research focusing on right/left hemisphere lateralization and integration, the angular gyrus, endorphin molecules, the cerebellum, memory, hyperactivity, and attention.

But can we afford to wait until all problems are solved before we begin to study the educational issues implicit in this research? When mass media begin to report discoveries, parents will expect us to respond.

The title of Restak's book, *The Brain: The Last Frontier,*[2] succinctly describes the challenges educators face. Look at where heart research and space exploration were ten years ago and then think about where brain research might be in ten years.[3] If we're going to respond to the chal-

Photo: Michael Sexton

lenge when it arrives full blown, we need to start now on a number of fronts, including the following:

Preservice and Inservice Education: It's a rare teacher education student who has a respectable background in cell biology, biochemistry, and neuroscience; and it's a rare inservice program that systematically introduces relevant brain research to its teaching and administrative staff. Even though the social science/behavioral orientation of our profession will probably continue, we need to prepare educators to understand the brain that really defines our profession. We ought to adapt our preservice and inservice programs so that we can become better acquainted with our own brains, and we ought to introduce our students to theirs.

Models and Metaphors: Miller[4] suggests that we have never understood any part of our body until we recreated it metaphorically and technologically outside our body. For example, the invention of the water pump led to a clearer understanding of the heart.

Since schools traffic heavily in metaphors, it might be useful to introduce brain studies into the school through the development and use of appropriate models and metaphors that define the brain and its functions for educators with a limited scientific background.

The computer (a swift idiot) has become the popular metaphor of the brain. The metaphor is flawed, though, which can lead to misconceptions about ways students process information, respond to instruction, and learn. If people perceive the brain to be little more than a computer, they will expect it to function as one and the student to behave as one.

Educators need to work with scientists to develop accurate and appropriate definitions, explanations, models, and metaphors of the brain that teachers and students can easily understand and use during this period when scientific information about the brain is limited in the schools.

The Educational and Medical Professions: Recent brain discoveries suggest that the educational and medical professions might have a lot more in common by the end of the decade than they do now. Research in chemical interventions (such as in hyperactivity) certainly affects both professions, as does research in nutrition, stress, endorphins, biofeedback, and brain growth patterns.

Brain discoveries may encourage us to move away from our traditional proactive/group/normative approach to our students toward the more reactive/individual/diagnostic approach the medical profession uses. Epstein's brain growth research and the increasing use of Individual Education Plans in our profession suggest some movement in that direction. School psychologists, speech pathologists, and others who work with student brain excess/deficit problems already function much as medical doctors do —scheduling students individually, focusing on diagnosis, prescribing treatments that others carry out, and so on. Further, educational specialists and aides, educational malpractice suits, voucher systems, and teacher internships all have an interesting medical ring.

Oddly enough, while the schools are nudging toward the medical model, the medical movement toward holistic medicine, preventive medicine, group medical practice, and childbirth and weight reduction classes all signal a medical interest in educating the patient.

Where all this will lead is unknown but it does suggest that the two professions should begin serious conversations. Both are deeply concerned with the development and maintenance of a healthy brain and body, and we ought to join together in our efforts. ■

[1]Herman Epstein, "Growth Spurts During Brain Development: Implications for Educational Policy," in *Education and the Brain,* ed. J. Chall (Chicago: National Society for the Study of Education, 1978), chapter 10; "Correlated Brain and Intelligence Development in Humans," in *Development and Evolution of Brain Size,* ed. M. Hahn (New York: Academic Press, 1979), chapter 6; "Some Biological Bases of Cognitive Development," *Bulletin of the Orton Society* 30 (1980): 46-62.

[2]Richard Restak, *The Brain: The Last Frontier* (New York: Warner, 1980).

[3]The following books were written for general readers: *The Brain, A Scientific American Book* (San Francisco: Freeman, 1980); Gordon Taylor, *The Natural History of the Mind* (New York: Dutton, 1979); Peter Russell, *The Brain Book* (New York: Hawthorn, 1979); Carl Sagan, *The Dragons of Eden* (New York: Random House, 1977); Barbara Brown, *Supermind* (New York: Harper, 1980).

[4]Jonathan Miller, *The Body in Question* (New York: Random House, 1978).

"During the 10-12 + growth spurt, female brain growth is about three times that of males. . . ."

JEANNE S. CHALL

A few years ago the Harvard Medical School and Beth Israel Hospital in Boston examined the brain of a severe dyslexic following the young man's accidental death at age 20. They discovered that his brain was physically different from the brain of a normal human being (Galaburda and others, 1978).

This is important new knowledge for educators. It strongly supports the inclusion of the neurosciences in the study of learning and in the evaluation and treatment of learning disabilities.

This is, of course, not the first evidence that learning is related to brain structure. Earlier theories of reading and language disability, such as that of Samuel Orton, were also based on theories of brain functioning, but the evidence on which these theories were based was indirect. The recent brain autopsy is perhaps the first direct evidence that environmental factors alone—home background, schooling, motivation—may not be sufficient to explain the reading and learning difficulties of some children. For them, neurological difficulties need also be investigated as possibilities. Indeed, the problem may lie in interaction of these various factors, the physical with the environmental.

There appears to be rather strong resistance to a brain-based hypothesis as a possible cause for reading and related learning disabilities. One reason may be that some children have been diagnosed as having neurological problems based on only a few short tests of limited reliability and validity. Another concern is that too much emphasis on a neurological hypothesis will lead teachers to consider such children unteachable. If so, this would be unfortunate; the evidence from theory, research, and clinical practice is that learning disabilities stemming from neurological factors are best treated with appropriate instruction. Reviewing a set of papers written by neuroscientists, another writer and I (Chall and Mirsky, 1978, p. 372) drew the following implication:

> The emphasis on education [in the various papers] may strike readers as ironic, for brain injury or neurological impairment or dysfunction . . . are usually regarded fatalistically, with the expectation that little or nothing can be done about them. Yet over and over again the evidence indicates that practice and stimulation at the right time will foster learning, particularly among those with brain injuries or dysfunctions. The neuropsychologists and neurophysiologists are saying that hope, not fatalism, is appropriate.

Another issue raised by the Boston discovery is one that educators have met in other contexts. Why do many readers start slowing up at around the fourth grade? It is interesting to note that the dyslexic young man had learned to read only to a fourth-grade level. Is this related to the recent retesting by the National Assessment of Educational Progress, which found an increase in reading scores to age nine (grade four) but not for the later grades?

Still another question concerns the number of children whose reading and related learning disabilities are neurologically based. Is it the 2 or 3 percent provided for under PL 94-142? Or 7 to 8 percent as some authorities on learning disabilities claim? Or is it 10 to 15 percent as reported by the Committee on Dyslexia and Related Reading Disorders? The figure accepted affects the planning and budgeting for diagnosis, remedial treatment, and total education of these children.

> ". . . learning disabilities stemming from neurological factors are best treated with appropriate instruction."

As with all important discoveries, this new knowledge may or may not be used constructively. The brain hypothesis can be a force for good, but we need to know much more about assessment and effective teaching procedures for such children and young people. We need to be cautious in classifying students without sufficient diagnostic information. We need also to exercise modesty in classifiying instructional programs as neurologically based when there is little or no evidence to support this claim. ■

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In the everyday sense of the term, there are no educational implications in recent research on the human brain. The reason is that neuroscience and education exist at different levels of study and abstraction. As a result, attempts to develop educational implications by equating educational issues to neurological phenomena, by overlaying education upon neuroscience, or by reducing behavior and psychological function to neural structure and physiology are not likely to lead to useful educational implications, in the sense of answers to practical problems important to teachers and administrators. Educational problems involve levels, contexts, and multivariate complexities not encompassed in neurological research.

In a less ambitious but more defensible sense of ideas worth thinking about, studies worth doing, and hypotheses about learning and teaching worth testing, there are important educational implications of the recent research on the human brain. Precisely because neuroscience, behavioral science, and educational research study different levels of related phenomena, research on the human brain can provide useful analogies, suggest new hypotheses, revise old theories, and even eliminate some otherwise attractive but unproductive ideas about teaching and learning.

I want to discuss educational implications at three levels—learning, teaching, and paradigms for educational research—that follow from a juxtaposition of research in neuroscience, behavioral science, and education.[1] From this research, we can seek a convergence, a pattern, a coherent whole, or a common direction that leads to defensible new hypotheses and ideas.

Learning

• *Learning is a generative process.* Many of the recent findings about the plans and organizations constructed in the frontal lobes of the brain (Luria, 1973), the encoding strategies of the cortical hemispheres (Gazzaniga, 1977), the attentional mechanisms of the brain (Beatty, 1977), and the influence over perception exerted by the descending reticular system (Dykman, 1970) closely complement recent research in cognitive psychology on memory, motivation, and attention (Wittrock, 1978a, 1978b, 1980; Wittrock and Lumsdaine, 1977). From these convergent data, I have developed one conception of human learning with understanding that differs from a currently popular behaviorist belief that learning is largely determined by immediate, sensory input from the environment (Wittrock, 1974, 1980). Instead, I believe the cortex, midbrain, and brainstem actively influence attention, perception, motivation, and the use of memory in the construction of meaning from experience. The intentions, dispositions, sets, and memories we bring to a situation influence our understanding of it to an impressive degree. As a result, we learn what we actively construct from being taught, not only or necessarily what the teacher attempts to tell us (Wittrock, 1978a, 1981).

Jerison (1977) states that the brain is a model builder. It functions to make sense out of reality by applying models to it. I do not mean to imply that structure in the environment is lacking, or that environmental stimuli are unimportant in school learning. On the contrary, the environmental stimuli, as they are selectively attended to and transformed, influence learning. The point is that recent research on the brain and some of the recent research in cognitive psychology indicate that the attentional and encoding systems of the brain, not only external stimuli, are actively involved in learning in schools.

• *Our brains have characteristic processes for encoding and storing information.* Analytic and synthetic processes, imagery and verbal processes, and simultaneous and successive processes are several of the sets of encoding processes frequently studied in neurology and in psychology (Wittrock, 1978a). Field-independence and field-dependence, focusing and scanning, and impulsivity-reflectivity are cognitive styles studied in psychology. Although the relationships among these different processes and styles are not yet well understood, one implication is clear. Individuals have several different ways to organize and transform information. Consequently, people learn and remember different things from the same events or external stimuli, depending on the organizational processes they use.

• *The arousal and attentional processes in the limbic system and brain stem and the planning and organization processes in the frontal lobes interact with each other and influence behavior and learning.* Attention is influenced by the plans and intentions constructed primarily in the frontal lobes, the descending reticular system, and the orienting mechanisms of the brainstem and limbic systems (Luria, 1973). In research in education and psychology, a debate has long existed over the merit of studying hypothetical cognitive processes, such as selective attention and motivation, as a way to understand human learning. Without overlaying neuroscience on education, recent research on the fundamental workings of the brain supports many of the related findings from the research on cognitive processes, such as attention, arousal, and motivation. In particular, research in neuroscience, psychology, and education converges on the importance of attentional and arousal systems in influencing behavior and learning.

• *Individuals differ in their uses of the attentional and organizational cognitive processes of the brain.* Neuroscience, education, psychology, and related fields agree on the importance of study of individual differences in cognitive processes. A useful conception of educationally meaningful individual differences is emerging from the relationships that appear in research in these areas.

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The conception centers on process-oriented aptitudes and process-oriented individual differences, which are the cognitive styles, strategies, schemata, and related background information of the learners. These process-oriented individual differences, better than age, sex, and IQ, promise to lead to productive treatments and intervention strategies that either match the learners' aptitudes or compensate for their lack of aptitudes.

• *Learning disabilities are sometimes caused by lesions of the brain, whose location and effects are increasingly becoming known.* With knowledge about brain function and damage, educators can begin to design remedial treatments that build on intact functions. They can seek available remedial medical treatments to enhance learning and behavior. Glass and others (1973) designed effective teaching procedures using spatial representations of verbal symbols to help aphasic patients who had massive left hemisphere damage to their brains. Without knowledge about brain malfunctions, such as those that occur in the aphasias, time and energy may be wasted on ineffective treatments, or expensive trial-and-error attempts to discover effective behavioral treatments.

Instruction and Teaching

• *Students learn and remember what they actively construct mentally during teaching and studying.* Students have responsibilities for attending to information, retrieving relevant memories, and elaborating on the relationships between information and memory. Because our brains actively enter into the construction of meaning, students and teachers have differentiated responsibilities for learning. Students are responsible for constructing sentences, images, inferences, metaphors, and the like to learn the information and encode it into long-term memory (Wittrock, 1978a, 1981).

• *Teachers facilitate attention, motivation, and the construction of mental elaborations of information.* With my conception of teaching as a generative process, the teacher also has new responsibilities for guiding attention, asking questions, providing images, propositions, hypostatizations, metaphors, similes, and stimulating motivation and arousal appropriate for the generation of mental elaborations by learners. In large part, teaching is the process of facilitating the learner's construction of appropriate mental elaborations of subject matter, concepts, and behavior to be learned.

"It is unfortunate that the simplistic notion of teaching to one or the other hemispheric process of the brain has become widespread and popular."

• *Repetition and reinforcement may not lead to sustained interest and attention.* Some of the older interpretations of the maintenance of behavior seem questionable in light of recent research in neurology and cognition. Repetition and reinforcement of behavior sometimes lead to disinterest. The brain responds at least momentarily to novelty, to the unexpected event, to discrepant information. For learning in schools, techniques other than reinforced practice, drills, and reviews seem likely to stimulate interest.

• *The multivariate reality constructed in the brain is more sophisticated and complicated than instruction is often designed to accommodate.* Instruction using a single objective or an assumption that a single meaning is learned seems naive. A variety of organizations, strategies of information processing, and sequences of instruction for different contexts, people, and subject matters seems more likely to accommodate and facilitate the sophisticated multivariate processes of our brains.

• *Instructional interventions should be timed to correspond with growth and development of the brain.* MacLean (1978) supports the position that the success or failure of educational interventions depends, in part, on their relation to the brain's developmental processes. He suggests that Head Start programs have succeeded or failed for the same reason. There is a parallel concept in developmental psychology. The relations between developmental neuropsychology and other areas of developmental psychology promise to lead to a match between the timing of instructional treatments and learner development. Knowledge about different rates of intellectual development of different groups or individuals coupled with an understanding of brain development with age could inform and improve the timing of instruction in schools.

• *Education, environmental stimulation, and nutrition influence brain growth.* One of the most intriguing areas for the construction of educational implications is research on the reactions of tissues and individual cells of the brain to environmental and nutritional stimuli. Although the findings are tentative, it seems that dendritic branches of neurons in the cortex sometimes increase in density in response to stimulating environments (Wittrock, 1980). Along with recent findings about the effects of nutrients (such as choline) upon the brain (Sitaram and others, 1978), the implications about environmental stimulation and nutrition are relevant to fundamental educational issues.

Instruction treatments and interventions also seem to be related to the learning of specific behaviors, facts, or concepts. It is clear that environmental stimulation, especially education, can be important for brain development (Chall and Mirsky, 1978). When these findings in neuroscience are juxtaposed with related findings in developmental psychology and human learning, it seems that education and environmental stimulation can have impressive effects on normal brain development and sometimes also on the remediation of function lost because of brain damage.

Educational Research

• *At least some paradigms for educational research should encompass the mental processes of the learners, their development, and individual differences in the study of learning from instruction.* Simplistic stimulus-response, input-output, paradigms commonly used in the study of teaching and instruction are not ideal for studying or understanding how people learn from teachers, or for building relations between education and the findings of the recent research on cognition and the brain, especially its processes and functions. Process-oriented models of learners' aptitudes and of teachers' activities that do not rule out the relevance of the brain's thought process to learning can lead to useful hypotheses about instruction and teaching, to a deep understanding of learning from instruction, and to practical and effective teaching procedures (Wittrock, 1978a). These process-oriented models are also becoming feasible for use in educational research.

• *Educational researchers who study learning and instruction cannot afford to remain isolated from neurology, neuropsychology, and related fields.* The growing unity of interests across these different levels and fields promises to benefit all of them, to improve the quality of hypotheses studied in education, and to improve the productivity and utility of the research studies in education.

It is important to conclude with a cautionary note, as Chall and Mirsky wisely did in the final chapter of *Education and the Brain* (1978). It is unfortunate that the simplistic notion of teaching to one or the other hemispheric process of the brain has become widespread and popular. As Chall and Mirsky indicate, curricula designed to avoid the teaching of skills such as reading or writing to certain groups of children who learn better with other skills can lead to serious gaps in achievement in culturally important areas of learning.

There are no panaceas for education in the recent research on the human brain. Neither are there any findings that indicate we should stop teaching culturally important skills or subject matters to any group of learners. On the contrary, when related to research in psychology and education, the research on the brain leads to some important hypotheses about educational research, learning, and the teaching of curricula and skills. I have presented some of these implications along with implications of my model of learning as a generative process. We should go slowly and carefully with the development of these educational implications, remembering the great difference in level of research between neuroscience and education.

In my opinion, one of the most important educational implications that follows from the juxtaposition of recent research in cognitive psychology, neuroscience, one that synthesizes many of these findings, is my hypothesis that learning with understanding, as it occurs in schools, is a generative process (Wittrock, 1974, 1980, 1981). ■

[1]The research on the human brain cited in this article is discussed at greater length in Wittrock (1978, 1980) and Wittrock and others (1977).

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Photo: James Foote

LESLIE A. HART

Last spring, the New York City Public Schools announced that 24,745 fourth and seventh grade students would not be moved ahead. Under a new "gating" plan, these students were found to be below minimally acceptable levels of reading achievement and were therefore candidates for corrective programs. A year earlier, they would have been passed to the next grade almost automatically.

The announcement dramatized a profound shift that affects schools everywhere. No longer may schools "process" students, as they have for generations, letting the blame for learning failure fall on child, parents, community, background, or other nonschool factors. The assignment has changed. Parents, public, and legislatures insist now that the school *must* bring about learning, at least to some standard—as yet dismayingly low.

But to be candid, as well as practical, do schools know how to raise achievement? Can we instruct so that satisfactory, reliable learning occurs? Surprisingly, until now the problem has never been faced. Now it is front and center, and formidable.

Fortunately, new inquiry, new theory, and new approaches are opening new doors. We do not have to go around again and again in the same fruitless small circles, rediscovering "new emphases" and "solutions" that go nowhere. We can actually move forward, onto fresh ground.

For the better part of a century, there have been weak, intermittent efforts to apply behaviorism to the needs of education. The results have been trivial, if not pathetic. Ironically, the "teaching machine" proved the sharpest embarrassment. By behaviorist theory, the learning obtained should have been near perfect. It wasn't. And, devastatingly, the trials made plain that one "program" of bit-by-bit instruction was likely to work no better than another, regardless of "logic" or the use or nonuse of "reward" and "reinforcement."

"The educator who sheds past confusions to see that the brain is the organ for learning enters an enchanting new world."

From its inception, behaviorism steered away from the brain, trying to escape old armchair introspection and other encumbrances. The policy made some sense; there was too little known about the brain to be of much help. But in recent times progress in the neurosciences, and in significantly related disciplines, has come with a rush. And in the last handful of years, we have acquired far more, profoundly more, understanding of the *human* brain.

We know that rats, mice, hamsters, and pigeons, subjects of endless behaviorist experiments, have only the merest trace of cerebrum, or "new brain," while in humans the cerebrum accounts for about five-sixths of the whole—and the cerebrum is where academic learning occurs. It is also nature's most incredible, stupendous, glorious achievement, the core and means of "being human."

The educator who sheds past confusions to see that *the brain is the organ for learning* enters an enchanting new world. Doors fly open on all sides; new pathways beckon, their potentials hardly explored, save by the persistent intuitions of observant teachers across the centuries. They saw, and sometimes demonstrated, what worked; yet rituals and rigidities and rat psychology resisted.

With the example of Piaget (ignored for 40 years) to inspire us, we are finally free to observe real children, in real (as opposed to contrived) activities; to study how youngsters and adults think; to absorb the implications of modern linguistics; to see the importance of self-image and of learner-driven effort ("generative," to use Wittrock's favored term); to view learning as a long, cumulative process, not as a response to one lesson; to take joy in perceiving the vast range of individual differences as resources, not awkwardnesses to be suppressed in the graded classroom or "diagnosed" as some kind of illness or disability. We can, in short, luxuriate and profit by seeing humans as human.

At the same time, we may emerge from a century of floundering to build useful theory, oriented to demonstrable educational outcomes and resting firmly on scientific knowledge of the organ for learning and its relation to human evolution and history. New understandings of the triune brain, of the two-sided brain, of an organ that grows and develops, influenced in good part by experiences and input, of brains that are "normal" even though they use strikingly different styles and strategies—all these can carry school organization and practices to a far more sophisticated level and bring educators more enjoyable and satisfying conditions of work.

The doors stand open. Those who go through them may well find what must be found if public schools are to survive. ■

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