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Survey of research on learning styles

Rita Dunn
St. John's University

Jeffrey Beaudry PhD
University of Southern Maine, jeffrey.beaudry@maine.edu

Angela Klavas
St. John's University

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SCIENCE EDUCATION

What We Know About
HOW PEOPLE LEARN



Volume II, Issue 2– Spring, 2002
California Science Teachers Association

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California Science Teachers Association

3800 Watt Ave., Ste. 100

Sacramento, CA 95821

(916) 979-7004

Fax: (916) 979-7023

E-mail: csta@cascience.org

President's Message

A Message from CSTA President, Dick Filson

Dear Colleagues,

On the subject of learning, we all must be experts. After all, everything we know was learned, we all spent a lot of time in school and, of course, we are all teachers. The problem is that experiencing learning without reflecting on the process does not, in itself, make us knowledgeable about learning any more than it makes us experts on how the brain works. Yet, the general public has high expectations for what teachers should be accomplishing with its children in the formal learning centers we call schools.

The articles in this edition of the *Journal* will help us to reflect on our learning and teaching experience. In that reflection, you may gain insight or just confirm what you have believed about the process. For example, I have believed for the greatest time that active learning is more effective than passive learning. I believe that students who bring a broad array of life experience to the classroom are quicker at making the connections that characterize “bright kids.” However, the information regarding brain research gives me insight as to why kids put in a

negatively stressful situation literally turn off their brain. If I want students to learn, I need to be sure that how I deal with the individual does not become an impediment to the process.

This edition of the *Journal* focuses on the central theme of learning and the brain. As in past issues, the *Journal* uses a thematic approach in selecting articles that will provide an in-depth treatment of a topic of interest. The articles selected are chosen for their readability and credibility. You will find that this issue's articles are provocative and enlightening. I hope that reading them will provide you with insight that will help you be a more effective teacher.

Best Regards,

Dick Filson, President

To Be Intelligent

by John Abbott

What does it mean to be broadly intelligent? Our schools and communities need to develop this capacity in our young people as they face the complex challenges of life today. Research on the brain and its infinite complexity can help.

For several summer holidays, when my three sons were young, we had swapped our home just outside Cambridge, England, with friends in Virginia. To our children, America was a land of long summer days, plenty of ice cream, and visits to national parks and historical sites.

Late one evening back in England, we were driving home from a day in the country with the children. My wife played a Garrison Keillor tape—the one describing his one-room schoolhouse in Minnesota. “At one end of the room there was a portrait of George Washington and at the other end one of Abraham Lincoln, beaming down at us like two long-lost friends,” Keillor drawled in his best Lake Wobegon style.

“That’s silly,” piped up 7-year-old Tom. “They weren’t alive at the same time, so how could they have been friends?”

I asked Tom how he knew that. “Well,” he said, “when we went to Mount Vernon they said how sad it was that Washington didn’t live into the 19th century—and you once told me Lincoln was born after Admiral Nelson was killed at the Battle of Trafalgar.” His logic, and the connections he had built, fascinated me.

Several years later, at a dinner party in Seattle, I recounted that story. “How I wish American elementary schools taught history as well as that!” mused our host, a professor of education.

“That’s silly,” said our adolescent Tom. “History lessons in school are boring. I just love everything to do with America!”

My wife interjected, “What’s your favorite subject?”

“It’s math, because my teacher always gets us to think about connections and patterns. That’s really interesting; I can see how things come together.”

Patterns and relationships, emotions, the need to sense, intrinsic interest, formal and informal learning, history dates, and mathematical formulas—these elements in Tom’s learning defy any logical structure. The process of learning is wondrously spectacular and messy, and it does not easily fit within a closely defined, classroom-based curriculum—particularly for adolescents.

Try as we might to accommodate children’s spontaneous questions, too often their natural enthusiasm is dulled by the needs of the system for order. Nevertheless, the capacity for self-organization (“I want to think this out for myself”) is valued more and more highly in our society, which is changing so rapidly that today’s questions are answered almost overnight. Some people call such an ability wits. In the north of England, people use an old expression—*nous*, a level of common sense that goes beyond book learning. It’s what the brain is all about.

The Complex Workings of the Human Brain

Medical and cognitive sciences, new technologies, and pedagogic research are helping us appreciate how the brain works. The human brain is the most complex living organism on Earth. Coveney and Highfield (1995) call it the “Cathedral of Complexity.” Although it weighs only about three pounds, it contains billions of cells (neurons). The total length of the “wiring” between the neurons is about 100,000 kilometers (62,150 miles). To illustrate: The total number of neurons is estimated to be greater than all the trees, in all the forests, on the entire Earth’s surface. The number of synaptic connections between neurons may be more than all the leaves on those trees. Susan Greenfield, when lecturing a group of 14-year-olds at the Royal Institution in London, compared the memory capability of all those neurons with that of 1,000 CD-ROMs, each one containing an entire *Encarta Encyclopedia*. The brain is, literally, a mind-boggling thought. Every human—including the most difficult adolescent—has just such a brain.

Biologists can tell us much about brain chemistry; but for educational practice, the concept of complexity helps us understand the layers of organization within the brain that act together, apparently miraculously, to handle not only memory, but also vision, learning, emotion, and consciousness.

The structures and processes of the brain are a direct response to the complexity of environmental factors faced by humans since our species appeared. Until about half a million years ago, the brain changed slowly through evolution. But our brains started to grow more rapidly as we learned to use language. Only within the last 30,000-60,000 years have we developed the capacity to be broadly intelligent.

What does broad intelligence mean? Archaeology and cultural anthropology show that humans developed many discrete skills over about a million years (social intelligence, technological intelligence, natural history intelligence, language intelligence); but only recently—say in the past 30,000 years—have we been able to combine these skills to create the broad intelligence that now gives us our amazing versatility. The cave paintings discovered by M. Jean-Marie Chauvet in southern France in 1994 date from this period.(1) Highly sophisticated, they bring social, technological, and natural history intelligences together. They seem to have leapt out of nothing—we know of no earlier primitive art. With the emergence of broad intelligence, modern man was created (Mithen 1996). Archaeology is starting to endorse Howard Gardner’s call to educators to work with all of children’s many forms of intelligence. That is what gives us our creativity.

How the Brain Flows

The brain can handle many situations simultaneously: historical facts are fitted into mathematical patterning when the brain is comfortably challenged in a nonthreatening situation. Psychologists and cognitive scientists call this a state of *flow*—a state you reach when you become so engaged in what you are doing that all tasks seem within your capability (Csikszentmihalyi 1990). This state enables us to react to our environment while also thinking about many abstract matters. The brain handles this complexity through several layers of self-organization and vast interconnecting networks. Once established, traces of these networks appear to survive almost indefinitely and are frequently used as solutions to new problems and as the basis for new ideas.

That is how, unconsciously, 7-year-old Tom built up his understanding of historical chronology.

Neurologists can now see some forms of memory in operation. Through magnetic resonance imaging (MRI), they watch specific patterns of activity within the brain light up on a computer screen. To the researchers' surprise, memory exists in many locations in the brain, not just one place. Some people liken memory to a hologram where the whole exists in all the parts. Memory traces seem to follow neural networks that the individuals—at the time of original thought—found most to their advantage, even if only for a short time. Nothing is ever irretrievably lost, though we still do not know how we can access memory more effectively at some life stages than at others. If part of the network is later activated, the brain may well question why it is not being asked to complete the original set of connections.

Going with the Grain of the Brain

All brain activity occurs spontaneously, automatically, in response to challenge. The brain does not have to be taught to learn. To thrive, the brain needs plenty of stimulation, and it needs suitable feedback systems. Effective learning depends on emotional energy. We are driven (the ancestral urges of long ago) as much by emotion as by logic. Children—and adults—who learn about things that matter to them are far more resilient and determined when they face problems than are people who seek external rewards. When in trouble, people with intrinsic motivation search for novel solutions, whereas extrinsically motivated people look for external causes to blame for their failure. The brain is essentially a survival system, and emotional well-being may be more essential for survival than intellectual well-being.

Too much stimulation, however, at any stage in life, turns a challenge into a threat. The brain deals with threat easily. It just turns off—as MRI dramatically shows. Give a person an interesting mental task, and many parts of the brain are seen to light up. Persistently insult that person, and the brain goes into a form of mental defense. The lights literally go out. Downshifting—a phenomenon long recognized by psychologists—is a strictly physiological defense mechanism. Research suggests that working effectively at a challenging task requires significant amounts of reflection—a critical part of brain functioning (Diamond 1995).

No two brains are exactly alike; thus, no enriched environment will completely satisfy any two people for an extended period. Challenge and interactivity are essential. Passive observation is not enough. “Tell me and I forget. Show me and I remember. Let me do it and I understand,” says the ancient Chinese proverb.

Learning What Matters

With our new understanding of the brain, we are in an excellent position to make it possible for people to become better learners. The implications of this new knowledge for society and for the economy are massive.

Ernest Hall, a successful English entrepreneur, understands the transforming power of learning. He was born in a northern industrial town near Manchester. His parents knew long periods of unemployment in the textile trade. One afternoon, when he was 8 years old, his teacher played a recording of “Apollo’s Lyre.” Ernest was spellbound; here was a form of beauty that was to transform his life. His family managed to obtain an old piano. By age 12, Ernest played so well that his parents urged

him to leave school and earn his living by playing the piano in pubs. “No,” said Ernest, “I love music too much to trivialize it. I will make enough money to play the piano properly.”

That is exactly what he did. For years he worked in the textile industry, with great success—and continued practicing the piano. By his early 50s, he had bought the closed-down Dean Clough Mills and created an amazing complex that today provides employment for more than 3,000 people in an array of high-tech and other businesses, including a mill—and that reserves a quarter of its space for art galleries, working studios, concert halls, and exhibition spaces. This complex vividly demonstrates that living, learning, and working—beauty and economic productivity—are all deeply interconnected.

To celebrate his 65th birthday, Ernest fulfilled a dream: He performed Bartok’s First, Second, and Third Piano Concertos, accompanied by the Leeds Sinfonia Orchestra. His CDs sell alongside those of the greatest pianists of our day.

Ernest believes in the potential of all young people to develop their particular abilities. “I discovered my interest,” he says, “before the crushing routines of my little school would have reduced me to a mere cog in a machine. Ability is not innate. It exists like a shadow of ourselves when we are willing to stand in front of a bright light. . . . We must say to every child, ‘You are special. You are unique; but to develop your genius you have to work at it, and stick with it year after year.’”

My son Tom comes from a privileged background. Young Ernest certainly did not. But creativity does not depend on privilege, nor does learning necessarily follow from teaching. Thus the old plaint of the teacher: “I taught them everything I ever knew, but they were so uninterested that they learned nothing!”

Contrast that with David Perkins (1992), writing in *Smart Schools*: “Learning is a consequence of thinking” (p. 78). We should remind every child of this statement each day.

How Do We Create Intelligence?

The understanding of learning will become the key issue of our time. The creation of intellectual capital has been going on with every generation for millions of years, with perhaps one exception—and that is what has happened over the past five or six generations.

Until the early 1800s, people learned in real-life, on-the-job situations. Then our industrial society required people to develop no more than a range of functional skills (such as reading, writing, and calculation) that allowed them to fit into the dull routines of manufacturing. Schools ignored the more inclusive skills that enabled people to make sense of things for themselves in earlier ages. For much of the past century or more, the spontaneous, deep learning of the Toms and Ernests of this world has existed largely outside the formal education system of Western industrial nations.

The ability to think about your own thinking (metacognition) is essential in a world of continuous change. Through metacognition, we can develop skills that are genuinely transferable. These skills are linked to reflective intelligence, or wits. As never before, the human race needs all the wits it can muster.

Being able to step back as a specialist and reflect—to honestly reevaluate what you are doing from a general perspective—is naturally developed in the rich, collaborative, problem-solving, and uncertain world of the apprentice, as opposed to the tasks, schedules, and measurable activities of the formal classroom.

Expertise requires much content knowledge—and metacognition. This deep reflective capability is what helps us develop new possibilities.

A New Model of Learning

A model of learning that could deliver expertise is ours for the asking. It would work on the basis of the biological concept of weaning—giving very young children plentiful help and direction, and then reducing this direction progressively as children master more and more skills. In this model, as adolescence ends, young people will already have taken full responsibility for directing their own learning. The age of 18 should mark not the beginning of independent learning but the age at which young people perfect that art and know how to exercise it responsibly.

Formal schooling, therefore, must start a dynamic process through which pupils are progressively weaned from their dependence on teachers and institutions and given the confidence to manage their own learning. Surely it should be the child who is tired at the end of the term and not the teacher.

To achieve this model of learning, we must reappraise the school system and its current use of resources and turn it upside down and inside out. Early childhood learning matters enormously. We must progressively show the youngest children that a lesson about American history, for example, can also be a lesson about how to learn how to learn and remember. As children grow older, they start to become their own teachers. The older the child becomes, the more he or she becomes a productive resource of value to the community (Abbott 1994).

In such a model, we should create smaller classes in the early years of elementary education (using developmentally appropriate

styles of teaching) and progressively provide children with an ever richer array of learning resources and situations. Learning need not be confined to an institution—it must become a total community responsibility. It is not merely teachers who can teach, not just pupils who need to learn, and certainly not just the classroom that can be the major access point to knowledge, information, and skills.

Our new understanding about learning is paralleled by radical developments in technology. The technological revolution holds the power to alter our education system, our work, and our culture. Indeed, this revolution puts learning and our traditional, conventional education systems on a collision course. The essence of the coming integrated, universal, multimedia digital network is discovery—the empowerment of the human mind to learn spontaneously, independently, and collaboratively, without coercion.

Such a new learning environment would be highly compatible with the natural functioning of the brain; with what we know about human aspirations; and, in particular, with the adolescent's need to feel involved and of value. It offers the greatest hope for an improvement in people's intelligence and the development of thoughtfulness.

The current crisis in learning has originated not so much in the failure of our classrooms as in the failure of our communities to capture the imagination, involvement, and active participation of young people. A society motivated by a vision of thoughtfulness will quickly recognize that broadly intelligent young people will revitalize the whole community. We must escape from the 19th-century assumption that learning and schooling are synonymous. Good schools alone will never be

good enough—we need communities that think differently, work differently, and are even designed and built differently.(2)

Such communities would make for a better, more exciting world in which living, working, and learning come together again and recreate vibrant, self-sustaining communities. I would love to live in such a world.

(1) The French Ministry of Culture Web site includes photos of the Chauvet cave drawings at <http://www.culture.fr/culture/gvpda-en.htm>.

(2) This article is based on the work of The 21st Century Learning Initiative (draft synthesis, December 1996).

John Abbott is president of the 21st Century Learning Initiative, c/o Rothschild Natural Resources, 1101 Connecticut Ave., N.W., Suite 700, Washington, DC 20036 (e-mail: polska@erols.com).

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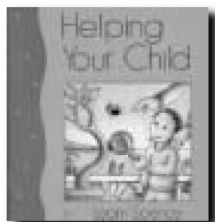
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How Children Learn

National Science Resources Center

But there is a strong hunch that the early learning, or lack of it, is crucial; and where the early learning has been missed there is an equally strong hunch that what was missed early cannot be faked or bypassed. —David Hawkins, Daedalus, 1983

For more than 50 years, cognitive scientists have been observing how children approach and solve problems. Their work has resulted in an impressive body of research about the learning process. Building on and modifying the foundation laid by Jean Piaget in the 1920s through the 1960s,⁽¹⁾ cognitive scientists have been able to draw some general conclusions about what is needed for effective learning to take place.

Cognitive science is a complex field. It is not our intention to explore all aspects of the field or to give a complete history of it. Our goal is to show how the findings of cognitive scientists support inquiry-centered science education at the elementary level. We will focus on two principles that have grown out of cognitive science and have important implications for effective science teaching and learning.

1) As part of the learning process, children develop theories about the world and how it works.

We now know that children construct understanding and develop theories about the world on the basis of their experience. Lauren Resnick describes the process as follows: “Learners try to link new information to what they already know in order to interpret the new material in terms of established schemata.”(2) The implication of this for educators is that it is important to begin building children’s experiential base in the primary grades by providing research-based, inquiry-centered experiences.

2) The development of the human brain follows a predictable path.

The developing biological structures in the brain determine the complexity of thinking possible at a given age. Educators must be aware of stages of growth and be prepared to teach what is developmentally appropriate for children in each grade throughout elementary school.

Incorporating these two basic concepts of cognitive science into an elementary science program can lead to the development of more effective learning experiences. In the following sections, we will explore some of the implications of these concepts.

The Role of Inquiry-Centered Experiences in Elementary Science

Educators have long debated the relationship between hands-on learning and book learning in the classroom. In the 1960s, some disciples of cognitive psychologist Jean Piaget were advocates of pure “discovery” learning; taken to the extreme, an advocate of this school of thought might suggest that the most effective way for children to learn about buoyancy would be to

give them a basin of water and a variety of floating and sinking objects and have them learn what they can from these materials. Left to their own devices, some children may discover that some of the objects float while others sink. The teacher would then be requested to help the children make sense of their findings.

Because experience has shown that most children need some guidance in order to learn, by the 1970s, many educators believed that a more realistic way to organize the classroom is through a combination of instruction and hands-on experiences.⁽³⁾ These educators acknowledged that hands-on experiences generate excitement and enthusiasm for children and provide them with valuable learning experiences. At the same time, the educators had come to see that it is impossible to learn everything this way; some things, such as the names of the planets and their position in the solar system or the concept of life cycles, need to be introduced by the teacher. The challenge for teachers becomes deciding how to integrate didactic instruction and inquiry-centered experiences.

In the past, many teachers have tended to rely on books and pictures to teach science concepts. When possible, some have used hands-on experiences to reinforce that learning. The problem with this approach is that students may have no real-life experiences that relate to this information. Children learn best when they can link new information to something they already know. Therefore, it is often most effective to introduce a new concept by providing children with inquiry-centered experiences. By doing so, educators provide students with a firmer foundation on which to attach the information they will receive later on from other sources. Lawrence Lowery summarizes these ideas: "Books are important. We can learn from them. But books can

only do this if our experiential foundation is well prepared. To learn geometry, we must have experience handling geometric forms and comparing them for similarities and differences. To learn about electricity, we must explore relationships among batteries, wires, and bulbs.”(4)

Furthermore, inquiry-centered experiences generate one of the most essential ingredients of learning—curiosity. Jane Healy writes, “As well-intentioned parents and teachers, we all sometimes end up taking charge of learning by trying to stuff [the child] rather than arranging things so that the youngster’s curiosity impels the process. Children need stimulation and intellectual challenges, but they must be actively involved in their learning, not responding passively.”(5)

Lowery believes that curiosity serves an even larger function. He describes it as a “trigger” that helps build crucial connections in the brain. These connections enable children to synthesize specific pieces of information, such as observations of color, form, and texture of an object, into the larger concept of one object with all these attributes. According to Lowery, the ability to synthesize is the essence of intelligence, and intelligence is the product of the quality and quantity of connections in the brain. He believes that educators would do well to capitalize on curiosity in the classroom because it sparks the formation of these connections.

The Implications of Cognitive Research

Children have a strong, innate desire to make sense of the world—and for good reason. With an array of sensory information flooding into the brain, coupled with growing motor skills and cognitive abilities, it is imperative for even the very young child to organize the data.

The way children begin to structure information in their minds depends on a variety of factors, including their individual experiences, their temperament and personality, and their culture. As these factors come together, children develop unique and enduring theories about the world and how it works. For example, a preschooler may observe that many living things, such as people, dogs, cats, and birds, have the ability to move on their own. On this basis, he or she may assume that one characteristic of living things is the ability to move on their own. This notion, while partially correct, discounts plants—a whole other world of living things. Yet to young children, this theory is satisfying, because it organizes a portion of their experience in a way that makes some sense.

Researchers have explained this “theory-making” ability in children in different ways. Howard Gardner has called such ideas part of the “unschooled mind.”(6) Resnick uses the term “naive theories” and maintains that children use such theories to explain real-world events before they have had any formal instruction.(7) Gardner and Resnick agree that even after starting school, children continue to hold on tightly to their early ideas and theories.

For example, consider Deb O’Brien’s fourth-grade class in Massachusetts.(8) In developing a unit on heat for her class, O’Brien began by asking students for their ideas about heat. To her surprise, she discovered that after nine long winters during which they had been told repeatedly to put on their sweaters when they got cold, the students were convinced that the sweaters themselves produced heat. This was their “naive theory.” O’Brien decided to give the students a chance to find out for themselves whether sweaters actually generate heat. She challenged her

students to design an experiment to demonstrate “sweater heat.” The students put thermometers in their sweaters to measure their temperature. Their hypothesis was that the temperature would rise, indicating that the sweaters were indeed “warm.”

O’Brien assumed that after observing a stable sweater temperature, the students would realize their misunderstanding, and the class would move on. But she was mistaken. Although the temperature of the sweaters stayed consistently at 68 degrees Fahrenheit, the students did not accept this evidence immediately. One student, Katie, wrote in her journal: “Hot and cold are sometimes strange. Maybe [the thermometer] didn’t work because it was used to room temperature.”

The students held to their beliefs through several trials. It was only after they had done everything they could think of—from keeping the thermometers in the sweaters for long periods of time, to moving the sweaters to another location, to wrapping the sweaters in sleeping bags—that some children were willing to consider other ideas about heat. In fact, Katie was one of the first to recognize that heat does not come from her sweater but from the sun and her own body.

This example is important because it illustrates how tightly children hold on to their theories and how difficult it is for them to relinquish them, even in the face of conflicting evidence. Nonetheless, O’Brien was able to help some children replace one set of ideas with more accurate information. She did so by following a clearly defined process. First, she allowed time for the children to express their naive theories by discussing what they thought about heat at the beginning of the unit. Second, she used that information to design the major part of the unit—having the students devise experiments to test their theories. Third, she let

the students use their own firsthand experiences as a starting point for reconsidering their old ideas and constructing new knowledge. Fourth, over the long term, she encouraged the students to apply that information to new situations. For example, next winter, when the children put on their sweaters, they will know that the heat they feel comes not from the sweaters but from their own bodies.

Many educators and cognitive scientists believe that this four-step process is at the heart of learning. The process is based on a theory of learning called *constructivism*. Constructivism promotes an important goal of science education—in-depth understanding of a subject, often called *conceptual understanding*. As Susan Sprague explains, “The constructivist model of learning contends that each student must build his or her understanding. In such a process, understanding can never be completed. Each student must work through his or her path toward deeper and deeper understanding and skills.”(9)

The process used by O’Brien has been refined and developed into a *learning cycle* that can be incorporated into the science curriculum. The learning cycle typically includes four phases.

1. Focus: Students describe and clarify their ideas about a topic. This is often done through a class discussion, where students share what they know about the topic and what they would like to learn more about. For the teacher, this is a good time to develop an understanding of students’ current knowledge and possible misconceptions and to consider how to incorporate this information into the planned lessons. This is also a time to spark excitement and curiosity and to encourage children to consider pursuing their own questions.

2. Explore: Students engage in hands-on, in-depth explorations of science phenomena. During this phase, it is important for students to have adequate time to complete their work and to perform repeated trials if necessary. Students often work in small groups during this phase. They also have the opportunity to discuss ideas with their classmates, which is a valuable part of the learning process.

3. Reflect: Students organize their data, share their ideas, and analyze and defend their results. During this phase, students are asked to communicate their ideas, which often helps them consolidate their learning. For teachers, this is a time to guide students as they work to synthesize their thinking and interpret their results.

4. Apply: Students are offered opportunities to use what they have learned in new contexts and in real-life situations.

As teachers begin implementing the learning cycle in their classrooms, they may notice that their students seem uncomfortable or reluctant to acknowledge that their naive theories were wrong. These reactions are the result of the internal conflict many students feel as they struggle to give up one set of theories for another. For many students, confronting their previous misconceptions and modifying them represents a difficult intellectual challenge.⁽¹⁰⁾ Therefore, it is important that teachers be aware of their students' struggle and be tolerant of this process and the frustration it may produce.

Ensuring That the Curriculum Is Developmentally Appropriate

While the learning cycle provides a framework for a pedagogical approach, educators must still decide what content to

include in the science program. To do so, they must understand children's intellectual development. Piaget's work with children resulted in a theory about intellectual growth that is based on the premise that all children pass through the same stages, in approximately the same order, as they develop. Although many researchers have questioned some of Piaget's ideas and postulated that he underestimated children's cognitive abilities, his theories still provide basic guidelines for educators about the kind of information children can understand as they move through elementary school.

The essence of the model described below, developed by Lowery and based on Piaget's work, is that we can maximize learning by presenting science concepts to children in a way that will be meaningful at each developmental level or stage.(11) The model is based on the human need to organize the information received from the senses in logical, coherent systems. For young children, these systems may be as simple as sorting objects by color or shape. The ability to sort and recognize patterns is particularly important, because children must master these skills before they can learn to read.

Children learn at different rates, however, and not all children achieve these milestones at the same time. In general, every class in a typical elementary school spans at least a full grade of cognitive developmental levels. The basic stages of cognitive growth, however, may be summarized as follows:

- Through the primary grades, children typically group objects on the basis of one attribute, such as color. When discussing plants, primary school students will be able to sort them by color or size, but they probably cannot perform both steps *at the same time*. In fact, it is a major cognitive leap when

children, at about fourth grade, are able to organize objects and ideas on the basis of more than one characteristic at the same time. The significance of this information for educators is that young children are best at learning singular and linear ideas and cannot be expected to deal with more than one variable of a scientific investigation at a time. For example, when observing weather, primary school students can study variables such as temperature, wind, and precipitation separately; it is not appropriate to expect them to understand the relationships among these variables. By the upper elementary grades, however, students will be able to consider such phenomena as how wind influences the perceived temperature (the “wind-chill” factor).

- Toward the end of elementary school, students start to make inferences. To some researchers, this marks the beginning of deductive reasoning. At this stage, students also realize that different plants or different animals can be classified into subordinate categories. For example, they understand that all crocodiles are reptiles but not all reptiles are crocodiles. At this stage of development, students are ready to design controlled experiments and to discover relationships among variables. When investigating the frequency of pendulum swings (number of swings in a minute) during a module on time, for example, sixth-grade students can experiment by changing variables, such as the length of the string or the mass of the pendulum bob, and then determining whether one or both of these variables affect the frequency of the pendulum swings.
- From this point on, students’ thinking processes continue to become more and more complex. At the onset of adolescence, students not only can classify objects by multiple attributes, they can also experiment with different organizational strategies. For example, they can decide how they want to organize a collection of plants. They may choose to

organize by color, size, shape, height, or leaf shape. They become more adept at manipulating these characteristics, which means that their scientific experiments can become increasingly more sophisticated. By age 16, students can understand highly complex organizational schemes, such as the periodic chart of elements and the structure of DNA.

If these developmental steps are not reflected in science instructional materials, there will be a mismatch between what children are capable of doing and what they are being asked to do. For example, it is inappropriate to expect a nine-year-old to understand the abstract concept of acceleration, yet some fourth-grade science programs include this concept. When this kind of mismatch happens over and over again, children do not learn as much as they could about science. Equally important, they do not enjoy science. For some children, this leads to feelings of failure and the development of negative attitudes toward science. If we can modify the curriculum to accommodate different stages of cognitive growth, we will take a big step toward solving such problems.

Key Points

- Inquiry-centered science provides an experiential base that children can relate to information they are acquiring through other sources. Because an experiential base is crucial for learning, it is appropriate to place hands-on learning first, before other kinds of learning take place.
- Children begin forming theories about the world long before they have accurate factual information, and they hold on tightly to these early ideas and theories. For this reason, educators need to be aware that it can take children a long time and many different encounters with a new concept to achieve conceptual understanding.

- To facilitate conceptual understanding on the part of students, the teacher needs to assume a new role in the classroom. He or she needs to create meaningful learning experiences that enable children to construct their understanding and deepen their knowledge of a subject.
- The way to maximize learning at each stage of growth is to present science concepts that are appropriate to the child's developmental level.
- The learning cycle—Focus, Explore, Reflect, Apply—has been applied in thousands of science classrooms. It is an effective way to implement the findings of cognitive scientists.

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Notes

(1) Piaget's seminal work, published in 1926, is *The Language and Thought of the Child* (London: Routledge). *The Psychology of the Child*, written with B. Inhelder, provides a good introduction to Piaget's ideas (New York: BasicBooks, 1969).

(2) L.B. Resnick, "Mathematics and Science Learning: A New Conception," *Science* (April 29, 1983): 478.

(3) Among the researchers who believed in a combination of "discovery" learning and traditional instruction was Jerome Bruner. His pivotal work is *Studies in Cognitive Growth*, by J. Bruner and M.J. Kenny (New York: John Wiley, 1965). David Ausubel, an educational psychologist, also espoused this view. His pivotal work is *Educational Psychology: A Cognitive View*, by D.P. Ausubel et al. (New York: Holt, Rinehart, and Winston, 1978).

- (4) L.F. Lowery, *The Biological Basis of Thinking and Learning* (Berkeley: University of California, 1992), p. 5.
- (5) J.M. Healy, *Endangered Minds: Why Our Children Don't Think* (New York: Simon & Schuster, 1990), pp. 72-73.
- (6) H. Gardner, *The Unschooled Mind* (New York: BasicBooks, 1991), p. 5.
- (7) Resnick, *Mathematics and Science Learning*, pp. 477-78.
- (8) This example is from an article by Bruce Watson and Richard Konicke: "Teaching for Conceptual Change: Confronting Children's Experience," *Phi Delta Kappa* (May, 1990): 683-85.
- (9) S. Sprague, "Beyond Explicit Standards for Science Education," in *Redesigning the Science Curriculum*, R.W. Bybee and J.D. McInerney, eds. (Colorado Springs: BSCS, 1995), p. 92.
- (10) Resnick, *Mathematics and Science Learning*, pp. 477-78.
- (11) See Lowery, *The Biological Basis of Thinking and Learning*, for a more detailed discussion of this model.

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Seven Strategies That Encourage Neural Branching

by Thomas Cardellichio and Wendy Field

Teaching strategies that overcome the brain's natural tendency to limit information can open students' minds to new ideas and creative mental habits.

Imagine trying to hit a baseball and noticing all the colors of the stadium, the advertisements, and the roar of the crowd. The overwhelming amount of stimuli might make it impossible for you to hit the ball.

When we are born, our brains have the potential to assimilate a large variety of stimuli. Over time, we develop mental routines and patterns in response to the stimuli that are critical to our lives. Scientists call the process by which we develop selective mental patterns “neural pruning.” It is a natural brain function since we could not possibly survive if we had to learn to interpret stimuli anew each time we experience them. We would be overwhelmed with input to the point of being unable to function.

Recognizing this, it is nevertheless advantageous to be able to attend, selectively, to many stimuli—to overcome our neural

pruning. In biological terms, we might call this “extending the neural network” or, in more poetic terms, “neural branching”—the opposite of neural pruning. Current research indicates that this type of significant “brainwork” strengthens the brain—creating more synapses between nerve cells—just as exercise builds muscle tissue.

The Effects of Neural Pruning

A personal example illustrates how neural pruning closes down our ability to perceive information. One summer, we participated in a workshop on visual thinking at the Metropolitan Museum of Art in New York City. In the first exercise, we observed a slide that was completely out of focus. What was visible was a blur with barely distinguishable smudges of color. We were asked to draw what we saw. In the next phase, the focus was adjusted slightly so that the blurs became unformed patterns of color. In the third phase, the focus was sharpened a little more so that the shapes became more obvious. Finally, the slide was brought completely into focus to reveal Rubens’s *Venus and Adonis*.

In the discussion that followed, the instructor asked us to comment on what we had observed. One of us, at phase two, thought he saw an angel and the Madonna. At phase three, he was sure he had this “problem” figured out. He knew it was a portrait of a 16th-century courtier. He was sure he could “see” a ruffled collar around the courtier’s neck.

During the discussion, the instructor made this point: “If you look for information, you won’t see what is there.” We were so conditioned to discover the content of the picture that we failed to notice or appreciate the aspects of color, line, patterns, and

other elements that were present in the object itself. We were imposing our meaning on the data, and in the process, we were creating something altogether wrong. The process we used was wrong, and the results obtained were wrong. When looking at a picture, our neurons had been predisposed to function according to a certain established routine.

The Implications of Neural Branching

Working to extend our neural networks has important implications for education. Good teaching requires that students have the opportunity to select and assimilate enough data to force them to challenge misconceptions and to create strong, accurate conceptions. They cannot do this if the curriculum or the methodology or the structure of the school is so rigid that students experience only the presentation of data without the opportunity to make sense of it. That kind of teaching only accelerates neural pruning where we want to encourage neural branching.

The first step in encouraging neural branching is to develop a structure or framework that will support the kind of inquiry we need to do both in the classroom and in the organization. We need to create a mechanism that will accomplish the same effect as blurring the focus on the slide projector so that we can look at familiar things with new eyes—the things that might not be obvious at first glance given our predispositions. In effect, we are trying to create the opportunity to look at something for the first time—before our mind-set becomes rigid.

The following seven strategies, or types of thinking, are particularly suited to extending the neural network. We have incorporated these strategies into our supervision and coaching of teachers and in our classroom teaching. Underlying all seven is

the assumption that questioning is a far more powerful way to encourage neural branching than is explication or narration. The seven strategies can shape a generalized structure for inquiry that should undergird the framework needed to apply these strategies in various arenas—particularly in the design of curriculum. Such a structure would consist of a series of questions that we could apply to new data or to our old paradigms.

The examples that follow show how we have used these strategies to effectively extend students' thinking in all areas of the curriculum.

Seven Strategies

1. *Hypothetical thinking.* Hypothetical thinking is a powerful technique for creating new information. It is said that Einstein developed his theory of relativity by asking, "What would it look like to ride on a beam of light?" Hypothetical thinking is a powerful stimulant to neural growth because it forces us to conceive of issues and consequences other than the standard and expected ones.

Here are examples of hypothetical questions one might use in a social studies class:

What would have happened if Columbus had landed on the West Coast of North America?

What if the colonies had lost the Revolutionary War?

What if Washington, D.C. were situated in Kansas?

The key to the use of hypothetical questions is not in asking the question itself but in the follow-up questions that clarify both the complexity of forces that create events and the interrelated web of circumstances that follow from them.

Hypothetical questions take the following general forms:

What if this had happened?

What if this were not true?

What if this had not occurred?

What if I could do something I cannot do?

2. *Reversal*. One of the techniques used in visual thinking to get outside the context or beyond the information is to blur the picture or turn it upside down. What is a verbal equivalent of turning the picture upside down? One possibility is to go backward from results to causes. We could ask, “What could have happened to create this situation?” Reversal is a specific kind of hypothetical thinking that highlights attributes of events or situations that might otherwise go unnoticed.

Here are a few examples of questions that use the reversal strategy:

What happens if I reverse the addends in a math problem?

Can I do this in a subtraction problem?

What if Nixon had been elected president before Kennedy?

What if your mother had your father’s job and your father had your mother’s job?

What if Japan had won World War II?

In some cases, asking students to generate other questions may be even more profitable than looking for answers.

General questions that solicit this kind of thinking are the following:

What caused this?

How does this change if I go backward?

What if I turn this upside down or sideways?

What if _____ had happened first?

3. *Application of different symbol systems.* Sometimes we get locked into rigid ways of thinking by applying the rules and procedures of particular thinking systems. Another way to extend the neural network is to apply a symbol system to phenomena for which it is not usually used. For example, we use language (the verbal symbol system) for interpersonal communication. What happens if we apply the verbal symbol system to a problem for which we ordinarily use the numerical symbol system? We could, for example, ask students to explain the Pythagorean theorem in words after we teach its mathematical representation. Continuing, we could ask students to draw a picture (visual symbols) of the Pythagorean theorem that shows us they understand it.

We can also move from verbal systems to quantitative systems. Students could graph or chart relationships in a social situation or in a literary work. Perhaps they could write an equation to show how human interactions are related.

General questions that prompt this kind of transference include the following:

Can I make this into a word problem?

Can I make this into a number problem?

Can I draw a picture of this?

Can I represent this in musical terms?

Can I act it out?

Can I make a dance to represent this?

4. *Analogy.* Another process of mental extension is to look for correspondences: What is like this? Looking for forced correspondences requires a greater “stretch”—more creativity. For example, how is the Pythagorean theorem like a cooking recipe? Looking for correspondences will create new insights about both elements of the analogy.

The general question that stimulates analogical thinking is “How is this like _____?”

5. *Analysis of point of view.* This viewpoint is the act of determining why someone holds a particular opinion or belief. It can be taught in a very behavioral and rigorous fashion by forcing students to question for details and evidence. Considering specifically the reasons why a person may hold a particular belief or opinion is a way of extending our own mind-sets.

The general forms of questions that provoke analysis of point of view are:

What else could account for this?

Who would benefit if I thought this?

What harm might occur if _____?

How many other ways could someone look at this?

What would _____ (for example, my mother) say about this?

6. *Completion.* When something is incomplete, there is a natural urge to complete it. If you show students a picture with a hole in it, they will immediately ask what was taken out before they attend to other aspects of the picture. This urge can be used to extend students' thinking in multiple ways. Here are a few examples:

Remove the conclusion from a short story and ask the students to create their own ending.

Tell the students that chapter one is about the Revolutionary War and chapter three is about the Civil War. Ask what they expect to find in chapter two.

Give the students the steps in a process or a solution (to a math problem, for example) with one or two steps missing. Ask what they think is missing.

This exercise involves greater or lesser degrees of ambiguity, depending on the context set. Two aspects of the exercise are important. First, questions should guide students toward reasonable answers—answers with evidence—so that they are forced to think of reasons for their responses. Second, encouraging a variety of answers will help students see that things can be connected in multiple ways, so that they do not become rigid in their approaches.

General forms of questions that provoke this kind of thinking include:

What goes in the blank space?

What is the missing piece or step?

How would you end the story?

Write the beginning of _____.

What if _____ did not happen?

7. *Web analysis.* One of our premises is that events and phenomena are related in complex ways. To make sense of things, our brains tend to oversimplify these relationships. The exploration of the complexity of relationships provides exercise that encourages neural branching. To experience this, answer the following questions with a partner, and during the process, reflect on how the experience feels to you:

How many people's lives do you think were affected by the deaths of Nicole Brown Simpson and Ronald Goldman?

How were they affected?

What would happen if people stopped drinking Coca-Cola?

How was subsequent history affected by the death of John F. Kennedy?

What happened when the first settlers in Puget Sound clear-cut all the timber?

At least two significant differences distinguish web analysis from hypothetical thinking. First, web analysis is concerned with what actually happened, not with possibilities. Second, hypothetical thinking may focus on one or two results; in web analysis the goal is to uncover the complex multitude of effects that may flow from a single source.

The power of web analysis to stimulate neural branching lies in moving beyond the obvious answers to uncover connections that we may not have realized previously. After we begin to "trace the web," the operative question becomes, "And what else?"

The following questions are the type that stimulate web analysis:

How extensive were the effects of _____?

How many effects can you imagine from _____?

Track the relationship of events following from _____.

How is _____ connected to _____?

The Ultimate Goal

All these strategies are related to one another in that they provoke divergent thinking. Using the strategies can extend students' neural networks and deepen their understanding—not just of the issue in question but also of the way our minds create meaning, of our biases. The more adept we become at understanding the tool that is our mind, the more power we gain over our own mental processes. It's like gaining the ability to see things as new, like the child who is full of wonder and questions, in order to force the brain into more assimilation and more accommodation.

The intent is not to diminish the importance of basic skills, content, or convergent thinking. These are essential for the growth of understanding. But there is a paradox in creating meaning. We need a framework to organize new information, to guide our search for more knowledge, to help us decide what should be selected for attention. We need a methodology to allow us to explore and to help us make sense of the results of those explorations. We need theory for its power to generalize and extend our knowledge. At the same time, we need to avoid becoming victims of our own knowledge, theories, and beliefs.

That is, we need a way to look beyond the information we have, beyond our theories, and beyond our beliefs.

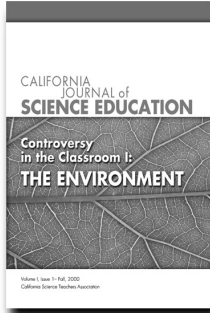
This is important work. What we are attempting to do is to protect students and ourselves from the curse of the closed mind. It is fundamental to our business as educators.

It is also important because we are not just talking about new ways of looking at the world. We are talking about plans for changing the structure of brains—educating brains that are fundamentally more powerful because they are able to assimilate a greater range of data and educating brains that are structured differently because they accommodate more diverse data. The goal is to create explorers who have an idea of what they are looking for, who have a methodology with which to search, but who come to the exploration with open minds so that, should they discover America, they will not assume they have landed in India just because that's where they intended to go.

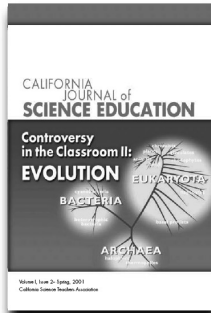
Thomas Cardellichio is principal of the Robert E. Bell Middle School, Chappaqua, NY 10514 (e-mail: crotonman@aol.com). Wendy Field is a teacher of Special Education at Westorcharde School in Chappaqua.

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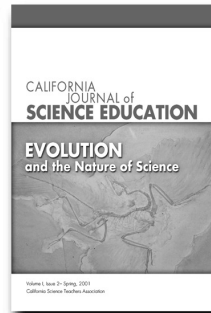
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On Using Knowledge About Our Brain A Conversation with Bob Sylwester, Professor of Education, University of Oregon

by Ronald S. Brandt

As biologists, medical researchers, and cognitive scientists learn more about how the human brain works, it is up to educators to keep informed, to study, and to apply what they have learned to the classroom.

Brandt: We're hearing a lot about the brain lately. There are books like you're a Celebration of Neurons (1995), feature articles in popular magazines, conferences, and so on. What accounts for this sudden interest?

Sylwester: People are intrigued by dramatic developments in research technology, the ability to “get inside” our brain and observe how it functions. Today, researchers can learn about blood flow, electromagnetic fields, and chemical composition of the brain without interfering with normal brain functioning. What's called functional MRI (magnetic resonance imaging) allows them to have subjects do something—like sing a song or do a math problem—and watch what parts of the brain “light

up” on a computer screen. Until MRI became available, most brain research was done only with animal brains or on people who had brain damage.

And along with imaging there are other technologies, like high-powered electron microscopes.

Right. With them, you can work at the cellular level—see neurons and synapses and the connections among them. And computers help, too, because rather than study a person’s brain you can study a computerized version of it. You can single out the serotonin system and see what the serotonin level is related to (for example, a new study says it’s related to autism). You can compare male brains and female brains, or an aggressive person with a non aggressive person, or a Republican with a Democrat (just joking). But all such group differences are now accessible.

For most of human history, the human brain was impenetrable; the skull got in the way. And even when you looked at a brain, you didn’t know what you were seeing—100 billion neurons, plus 10 times as many glial cells (support cells). How many is 100 billion? Well, there are about 100,000 hairs on the average head, so that would be all the hairs on the heads of a million people—that’s how many neurons you have in your brain. You can put 30,000 neurons into a space the size of a pinhead. Without modern technology, it was impossible to study the brain.

This whole field is very new, then.

Yes. Modern brain research began about 30 years ago with brain hemisphere studies. Roger Sperry worked with about two dozen people with epilepsy whose doctors had completely severed their corpus callosums. Today, if a person suffers from

epilepsy, a surgeon can locate the problem in a particular part of the brain—maybe less than a cubic millimeter—and, using advanced technology, possibly excise just those few neurons that need to be removed.

There's another reason for interest in our brain. If you have brain scans and nothing else, all you have is pretty pictures. But with this new information we've had a parallel boom in theory development. For example, William Calvin (1996) has identified what he thinks is the location and coding system of intelligent behavior—a horizontal wiring pattern in the top three layers of the cortex. If he's right, it could do for brain science what the discovery of DNA did for genetics.

With all this activity, do you expect a steady stream of new information about the brain in the years ahead?

Oh, yes. In science, when there's a big technological breakthrough, researchers start working on questions that until now were unanswerable. And as pieces of knowledge start coming in, they begin to see how things fit together. So eventually, we'll have the universal brain theory. We'll be able to deal with consciousness: how we know what we know and how we know we know it.

Naturally, educators are interested in all of this. They are looking for ways they can apply the new knowledge from brain research in their schools. What do you say?

Well, I think we've done it all along, but we didn't call it brain research. If you're a teacher, you're dealing every day with about 100 pounds of brain tissue floating several feet above the classroom floor. Over a 20- or 30-year career, watching how

those brains react, what they like to do, what they do easily and what with great difficulty, you're going to try to adapt your procedures to what works with brains. So, at that level, teachers have always been brain researchers. We've known, for example, how long a lesson should be to hold student interest. We've known that more boys have trouble with reading and writing than do girls, and that young children can pick up a foreign language more easily than adults can. But we didn't have a biological substrate for that. Now, we're beginning to add this biological dimension that helps us understand why these things are true.

You know, people were successful breeding dogs and horses long before DNA was discovered 40 years ago. It's taken 40 years to move from animal breeding to genetic engineering. So it took a while to find practical applications of this monumental discovery.

So what about practical applications of neuroscience?

We must take the time and effort to learn all we can about our brain—then figure out what to do about it. We teachers never really knew what was going on in those kids' brains. Now we have a chance to get beyond compassion and frustration. But first we have to really understand.

What is brain-compatible teaching?

I'm hesitant to use that term because it seems too pat. It seems to negate everything positive that teachers have been trying to do in the past. When the neurosciences come up with a discovery, it usually isn't a big surprise to most educators. For example, teachers have long encouraged students to find patterns and connections

in what they've learned, but new knowledge about our brain may help us discover new ways to help students expand their knowledge. And the best teachers know that kids learn more readily when they are emotionally involved in the lesson because emotion drives attention, which drives learning and memory. It's biologically impossible to learn anything that you're not paying attention to; the attentional mechanism drives the whole learning and memory process. Teachers know that emotion is important; they just don't always know what to do about it.

The point is that teachers need to study many things—biology, anthropology, psychology, and other subjects—and make their own discoveries about improving instruction.

Let's take attention research, for example. For very good reasons, our brain evolved to be good at sizing things up quickly and acting on the basis of limited information. This has big survival value, because it keeps you from being eaten by predators. You don't need to know how old they are and whether they're male or female; you just get out of there as quickly as you can. But because of this tendency of our brains to make quick judgments, we go through life jumping to conclusions, making a mess of things, and then having to apologize.

So we're very good at rapidly sizing things up and acting on limited information, but we're not so good at the reverse—anything that requires sustained attention and precision, like worksheets. That doesn't mean worksheets are bad; it depends on how you're using them. But some are clearly not used appropriately.

I've heard you say that our profession needs to move from dependence on social science to greater emphasis on biology. What do you have in mind?

Throughout history, educators have worked with brains—with limited information on how brains work. In this century, we have turned to the social scientists, who don't know about one brain but do know about bunches of them. So our professional education has focused on negotiating behavior with a group of kids, on allocating energy and resources.

Now, the social scientists could be compassionate about something like dyslexia; they could tell what percentage of the population would have the problem, but they couldn't solve it. Biologists look at underlying causes; they can help us understand what dyslexia is. The problem is that biologists deal with neurons and synapses and blood and tissue, which most educators didn't study in their professional preparation.

But in the years ahead, they will?

They'll have to. Teacher education programs will have to change. I can't imagine a person preparing to become a teacher these days without having access to cognitive science.

What would you emphasize if you were teaching future teachers?

The first thing would be that we are basically a social species. We are born with an immature brain and have a long childhood, so we have to depend on other people to take care of us in childhood. The marvelous thing about our maturation process is that our individual brains develop very differently—just like the files individuals may later create in their computers. Our brains develop in their own way, which lends credence to the idea of multiple intelligences and specialization. When we think about implications of our social brain, we see that everybody in a community must know how to do some things, such as communicate, but not everyone has to be able to repair automobiles.

Another obvious implication is the need to consider whether a particular learning task is individually oriented or socially oriented. It's foolish and wasteful to teach something to individuals if it's really a socially oriented behavior. I mentioned worksheets earlier. I saw a worksheet recently on which elementary students were supposed to list the five best qualities of a president—and hand it in with no discussion or feedback. Now, that's the kind of task we humans do more easily and naturally through discussion. It's not like a worksheet of multiplication problems, which is an individual task.

Another thing a biological approach can do for educators is change the way they think about education. For example, we talk about “higher order” and “lower order” as though one is much more important than the other. But it's really quite remarkable that we have the ability to remember a simple fact like where we're supposed to be at 12:30. If you can't remember the name of the restaurant where you're supposed to meet somebody, it may be lower thinking, but it's critical.

Another misconception is that the really important things are the hardest: Tasks that require a lot of energy and effort, like calculus, are the most significant. Biologically, that's just wrong. The way your brain looks at it, if it's important, it has to be a fail-safe operation—like digital competence, the ability to pick things up. If it's really important, you don't have to go to school to learn it; you can do it quickly and easily.

Why is it that the same kids who learned to speak their native language with no formal schooling—and who could have learned any language in the world the same way—have so much trouble learning to read and write? The answer scientists give is that reading and writing aren't nearly as critical to survival as is oral competency. That doesn't mean we should ignore the unnatural

things, but it does mean that we sometimes get our priorities wrong when we talk about standards and rigor and so on. We need to remember that from a biological standpoint, importance and difficulty are not at all the same.

You've said that in the future, teachers will know more about the brain. In the meantime, what advice can you give today's educators?

First, as I said before, take the time to begin learning about this. Read books by educators and by the brain scientists themselves. Exciting new books are being published almost every week.

Second, think about how what you're learning applies to education—but broadly, not narrowly. We don't need catchy program titles. We do need to study and contemplate, discuss and explore. If something sounds like a good idea, try it. And don't worry too much about making exploratory mistakes. We have this marvelous student feedback system; when we try out inappropriate ideas on our students, they let us know.

Last, don't promise too much. You aren't going to be able to boost SAT scores with this knowledge; it's just too early for that. And many important brain properties, such as metaphor, compassion, and love, aren't measurable. By all means read and study. By all means try new ideas. But don't overpromise.

Robert Sylvester is Professor of Education at the University of Oregon, Eugene, OR 97403-5267 (e-mail: bob-sylvester@cmail.uoregon.edu). Ronald S. Brandt is Assistant Executive Director, ASCD, and Consulting Editor, Educational Leadership.

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New Research on the Brain: Implications for Instruction

by Douglas Carnine

Gerald Edelman's work on the capacity of the human brain to categorize in connected ways has direct implications for educators.

The dominant view of perception, recognition, memory, and learning originated with Plato: the brain is a block of wax; the world, a signet ring. This interpretation gained credence from a series of neurological discoveries, beginning in the late 19th century, which suggested that the brain consists of a collection of highly specialized functional regions. The doctrine of localization of function has strongly influenced many educators.

According to the currently modish learning styles movement, specific locations in the brain are associated with various functions—auditory, visual, tactile, and so forth—that are thought to be areas of “strength” or “weakness,” depending on the individual. Once an individual’s functional strengths have been identified, instructional methods that play to those strengths should be selected. With reading styles, for example, the language-experience approach emphasizes visual and tactile

functions and so would be appropriate for a child with visual and tactile strengths.(1)

More recent research on the brain, by Gerald Edelman, Nobel laureate and director of the Neurosciences Institute at Rockefeller University, challenges such a simplified view of localization.(2) Israel Rosenfield describes Edelman's view of the brain:

What look like localizations are different ways of grouping stimuli —parts of a process of creating possible appropriate combinations and orderings of stimuli. . . . The “specialized centers” are just part of the larger combinatory tactic (the procedures) of the brain.(3)

The central procedures in Edelman's scheme are categorization and recategorization—in perception, in recognition, and in memory. Rosenfield summarizes these three operations.

- “How we perceive stimuli depends on how they are categorized, how they are organized in terms of other stimuli, not on their absolute structure. . . .”(4)
- “Recognition of an object requires its categorization. And categories are created by coupling, or correlating different samplings of the stimuli.”(5)
- “We do not simply store images or bits but become more richly endowed with the capacity to categorize in connected ways.”(6)

Categorization and recategorization might be viewed as the overriding activities of the brain, serving as basic mechanisms for various brain functions. A cornerstone of the capacity to categorize is the learner's ability to note instances of sameness. The role that noticing samenesses plays in learning has important implications for instruction.

At first glance, categorization might appear to be a mundane activity. After all, membership in a category obviously requires an attribute of sameness: all vehicles share certain characteristics. However, noting sameness can be far more creative than merely classifying objects as vehicles.

For example, near the turn of the century, a German physician was vacationing in Egypt. He was asked to treat a severely stricken boy who had been bitten by a cobra. When he inquired about the incident, the physician found that the boy's father had been bitten first but lacked the life-threatening symptoms present in his son. The father said that he had been bitten on two previous occasions, with the severity of the symptoms diminishing each time.

When he returned to Germany, the physician hypothesized that the same thing might happen with diphtheria, which was ravaging Europe at the time. He began a series of experiments in which he injected horses with increasingly potent doses of diphtheria bacilli until the horses developed antitoxins against the disease. Then he developed a serum from the blood of the horses. The serum led to a vaccine that immunized children against diphtheria.

Just as exposure to snake venom created immunity for the Egyptian boy's father, so injections of the diphtheria serum created immunity in European children. Today we have vaccines for polio, measles, and so forth. Immunization is a dramatic example of the importance of noting samenesses.

At the other extreme are cases in which we construe samenesses that are not only commonplace but also incorrect. Rosenfield notes that the mind is not a block of wax: learners are active as they categorize and recategorize. "But neither can one predict what constitutes information for an organism. The brain

must try as many combinations of incoming stimuli as possible, and then select those combinations that will help the organism relate to its environment.”(7)

Why Mistakes Make Sense

There is no way to “make” a learner focus on the combination of stimuli (i.e., note the samenesses) that the teacher wants to teach. Moreover, a student who learns an unintended sameness will make mistakes—perhaps trivial, perhaps significant. How students *mislearn* by noting samenesses illustrates the educational relevance of this basic brain activity. Incidents of such mislearning begin in preschool and continue through the elementary and secondary grades.

Very young children know that the name of an object stays the same even after the orientation of the object has changed. For example, when a chair is turned to face the opposite direction, it remains a chair. Consequently, in preschool, when a *b* is flipped to face the opposite direction, children often assume that it still goes by the name of *b*. Making this error doesn’t necessarily imply that a student’s visual brain function is weak or that the student would benefit from a kinesthetic approach to learning lower-case letters. Extensive research has shown that students are more likely to confuse objects and symbols that share visual and/or auditory samenesses, such as *b* and *d*.(8)

In solving simple computation problems, such as $24 + 13$, first-graders learn that they can start with the bottom number in the units column or with the top number: $4 + 3$ equals 7, and so does $3 + 4$. The sameness they note is that these problems can be worked in either direction, from top to bottom or the reverse. Soon thereafter come subtraction problems, such as $24 - 13$.

Students can still apply the sameness learned in addition, thinking of the difference between 4 and 3 or between 3 and 4 and always subtracting the smaller number from the larger. However, when students encounter a problem such as $74 - 15$, applying the sameness noted earlier leads them to subtract the smaller from the larger number and come up with the answer 61. Such a mistake is a sensible application of a mislearned sameness.

The next example of learning an unintended sameness comes from second-grade spelling. Hispanic students in the primary grades were doing very well in a basal spelling program. Such words as *site*, *kite*, *bite*, *high*, *sigh*, and *eye* were introduced on Monday and practiced in the same order until a test on Friday. A consultant noted that the students scored very well on the Friday test; the class average was over 80% correct. However, he suspected that the students had learned some samenesses that were not intended by the publisher or the teacher: for the first three words the students wrote the letter for the first sound and then wrote *ite*; for the next two, words, they wrote the letter for the first sound and then wrote *igh*; for *eye*, they simply remembered how to spell the word.

To test for this unintended sameness, the consultant had the teacher present the same six words again—but in a different order. The class average fell to below 40 percent correct. The word spelled correctly most often was *eye*, the one odd word that the students had to remember how to spell because it didn't fit a pattern, didn't exhibit a sameness.

Or consider the following example from reading. Many basal readers restrict vocabulary during grades 1 and 2 to a few hundred words and emphasize reading for meaning, using context clues and pictures. The sameness that students learn from

reading basal stories is to memorize a few hundred words, relying on pictures and context. In most third-grade basals, however, there are few pictures and many, many more words—too many for low-achieving students to memorize. The inappropriate sameness learned by low-achieving students isn't revealed until third grade, when they “blossom” into remedial readers.

Or consider a fourth-grader's strategy for solving math word problems, which she derived from a sameness she found in the word problems she had previously encountered. This is her description of the rules she learned: “If there is lots of numbers, I add. If there are only two numbers with lots of parts, I subtract. But if there is just two numbers, and one is a little harder than the other, then it is a hard problem, so I divide if they come out even, but if they don't, I multiply.” A unique strategy, perhaps, but one that had proved successful in her experience.

Let me offer a final example from the area of study skills. The student who learns to find a word in a glossary by searching page by page, beginning with the first page, will quickly give up on using a dictionary. Treating a dictionary in the same way as a glossary—turning page by page from the beginning—proves to be too slow, particularly if the object of the search is the word *zenith*.

These examples are from elementary school, and it can be difficult to appreciate the universality of the problem because the “samenesses” are all so familiar. In the next example, imagine that you are the learner, looking for samenesses. The concept is *Zug*. Study the examples, and then solve the two problems.

a. Zug	20	b. Zug	24
	<u>15</u>		<u>18</u>
	5		6
c. Zug	21	d. Zug	8
	<u>7</u>		<u>2</u>

If you filled in the blanks with 14 and 6, you noted an “incorrect” sameness. Zug does not mean: “Find the difference between these numbers.” I’ll return to Zug below.

Inducing Intended Samenesses

The brain’s search for samenesses has little regard for the intentions of educators. The examples above show some of the ways in which students often learn unintended samenesses. However, recognizing the brain’s search for samenesses does more than explain student misconceptions. It can also guide the development of more effective curricular activities. The goal is to develop activities that help students learn important sameness. Such activities should also keep students from learning inappropriate samenesses, and they should call attention to unintended samenesses that students are likely to learn.

To reduce confusion between *b* and *d*, for example, the curriculum designer can separate the introduction of these letters over time.(9) When *d* is introduced some time later, a teacher could stress the differences between *b* and *d*, using visual discrimination tasks before introducing auditory discrimination tasks.(10)

In preparing students for subtraction that involves borrowing, the curriculum designer can emphasize the ways in which borrowing problems are not the same as addition problems and

simple subtraction problems. To highlight these differences, the designer might present a series of simple problems.

$$\begin{array}{r} 1 \\ -7 \\ \hline \end{array} \quad \begin{array}{r} 7 \\ -1 \\ \hline \end{array} \quad \begin{array}{r} 5 \\ -2 \\ \hline \end{array} \quad \begin{array}{r} 2 \\ -5 \\ \hline \end{array}$$

Students would be told that they had to subtract the bottom number from the top number. The students would then cross out the problems that they couldn't work and write the answers to the problems that they could work. This activity reduces the sameness between addition and subtraction by sensitizing students to the consequences of having a smaller number on top.

Let's revisit Zug. Study examples *e* through *j*, which are all examples of Zug. Then try *c* and *d* from the previous set of Zug problems.

$$\begin{array}{r} \text{e.} \quad 25 \\ \quad \underline{15} \\ \quad \quad 5 \end{array} \quad \begin{array}{r} \text{f.} \quad 25 \\ \quad \underline{10} \\ \quad \quad 5 \end{array}$$

$$\begin{array}{r} \text{g.} \quad 20 \\ \quad \underline{10} \\ \quad \quad 10 \end{array} \quad \begin{array}{r} \text{h.} \quad 20 \\ \quad \underline{8} \\ \quad \quad 4 \end{array}$$

$$\begin{array}{r} \text{i.} \quad 6 \\ \quad \underline{2} \\ \quad \quad 2 \end{array} \quad \begin{array}{r} \text{j.} \quad 16 \\ \quad \underline{8} \\ \quad \quad 8 \end{array}$$

The correct answers for *c* and *d* above are 7 and 2. Zug means: "Find the greatest common factor." Examples *e* through *j* are better for teaching the concept of Zug because those examples were constructed following research-based guidelines for teaching samenesses.

Selecting and Sequencing Examples

Among the guidelines for selecting and sequencing examples (such as those for Zug) are the following:

- ▶ Select examples that preclude unintended samenesses.(11) In examples *e*, *f*, *h*, and *i*, the answers do not equal the number that results from subtracting the lower number from the upper, and the unintended similarity is precluded.
- ▶ Present minimally different examples to highlight unintended samenesses that students need to reject.(12) In examples *e* and *f*, the top numbers and the answers are the same, but the answers cannot result from subtracting. Such minimally different examples are relatively easy to compare.

I will illustrate these two principles by reporting the results of a study that compared a videodisc curriculum designed to teach fractions according to research-based guidelines with the best basal math program that could be identified.(13)

The first principle—eliminating unintended samenesses—can prevent students from forming misconceptions. Basal math texts introduce fractions as parts of a pie: $1/3$, $2/3$, $3/3$, $1/4$, $2/4$, and so on. The text for the following year introduces mixed numbers, but the fraction is still less than one, still just part of a single pie. Thus students have at least two years to “learn” that a fraction always represents a portion of a pie. They can deduce (and be reinforced for deducing) the “fact” that all fractions are the same in that they represent part of a whole. In the third year, students encounter such fractions as $4/3$, a new wrinkle that causes bewilderment for low-achieving students. To deal with this seeming violation of the sameness they have learned, many of these students draw a pie with four parts and shade three of them.

This confusion was reduced in the research-based curriculum by presenting a full range of examples (e.g., $2/3$ and $5/2$) from the outset. Students were given this rule to explain how all fractions are the same: “The number on the bottom of the fraction tells how many parts in each r group. The top number tells how many parts we have.” This rule applies equally well to improper ($5/2$) and proper ($2/3$) fractions.

The second principle—sequencing minimally different examples—can alert learners to unintended samenesses. The National Assessment of Educational Progress found that many students had learned an unintended sameness about denominators in problems involving the addition of fractions.⁽¹⁴⁾ The students had learned to “do what the sign says.” This sameness derives from students’ experiences with whole numbers and with multiplying fractions. When students multiply $1/3 \times _$, the denominators are multiplied. When students apply this sameness to addition ($1/3 + _$), they add the denominators to get $2/5$.

The basal program we studied does not deal with this unintended sameness. It teaches adding and subtracting fractions in one unit and multiplying and dividing fractions in another. Students receive no instruction or guided practice in distinguishing addition of fractions from multiplication of fractions.

The research-based curriculum, on the other hand, addresses this unintended sameness directly. Students are told that, when they add or subtract, they simply copy the denominator in the answer. Adding $2/3$ and $1/3$ is like adding two apples and one apple. The answer is three thirds (or apples).

The research-based curriculum presents minimally different examples: $2/3 + 1/3$ is transformed through videodisc animation into $2/3 \times 1/3$ by rotating the $+$ sign to make a \times sign. By

encountering minimally different problems, students have opportunities to decide what to do when they add and what to do when they multiply.

The guidelines for selecting and sequencing examples are important tools for educators, but they are not sufficient by themselves. Particularly at the secondary level, more sophisticated tools are also needed, such as multistep procedures and unifying principles.

Multistep procedures. A multistep procedure requires students to carry out the same sequence of actions in solving a variety of problems. The explicit procedure informs students that two problems are the same because they can be solved by following the same steps.

The research on story grammar illustrates the use of such a multistep procedure.⁽¹⁵⁾ Many short stories adhere to a set structure: a major character encounters a problem, acts to overcome that problem, and ultimately resolves it in some way. Students can learn to identify first the main character, then the problem, then the actions taken to resolve the problem, and finally the ultimate resolution. Students learn that, because many stories share this structure, the story grammar questions are useful in “making sense” of stories.

The need to teach students an explicit multistep procedure for comprehending even simple stories was driven home when I observed a first-grade teacher working with a reading group. She asked a hodgepodge of literal and inferential comprehension questions as the children read “The Boy Who Cried Wolf.” The students were learning the sameness that the purpose of reading is to remember isolated facts about a passage. If the students had learned a multistep procedure based on story grammar, they

could have identified the boy's problem as boredom, his solution as crying wolf (which did relieve his boredom), and the resolution as no one believing him when he cried wolf in earnest. With this type of summary, the children could have discussed the theme of the story intelligently. More important, they could apply the same procedure to many other stories. A more sophisticated story grammar that incorporates twists of plot, clues about characters, and so on has also been taught successfully to high school students.(16)

Unifying principles. A unifying principle is another way of showing how things are the same. Identifying unifying principles is particularly important in the sciences and social sciences, in which students are inundated by a great number of seemingly unrelated facts and concepts. According to one estimate, students would need to learn a new biological concept every two minutes in order to cover the content of a high school biology textbook. A typical biology textbook introduces twice as many new concepts in a year as the American Foreign Language Association recommends for foreign language learners. Most students try to remember some of the new vocabulary in biology—at least until after they take the next test.

One way of handling this information overload and the attendant misconceptions about the nature of science is first to identify the underlying principles of a discipline. The concepts necessary to understand the underlying principles can be taught initially. Then students can learn about the unifying principles themselves—and finally about the application of the principles.(17) For example, earth science covers a wide variety of phenomena in the solid earth, in the oceans, and in the atmosphere. Yet textbooks do not emphasize the underlying principle of con-

vection. Prerequisite to understanding convection—the circulation of heat through a medium—is the understanding of many other concepts: heating and cooling, the implications for expansion and contraction, subsequent rising and sinking, and, finally, areas of high and low atmospheric pressure.

After the concept of convection has been taught, it can be used to explain ocean currents, air currents, and many phenomena in the solid earth. All of these phenomena are the same in that they are caused at least partly by convection. The unifying principle of convection reveals a fundamental sameness in many phenomena in the ocean, atmosphere, and solid earth. Instruction along these lines leads to a more sophisticated comprehension of science principles and their application.(18)

Practice and Review

Though critical for the acquisition of new content, learning the appropriate samenesses does not touch on many other important aspects of learning. For example: If students are to retain newly acquired samenesses, they should practice until they can consistently respond correctly.(19) In the basal math program critiqued above, the skill of finding the least common multiple was introduced in one lesson, disappeared for seven lessons, was then reviewed in one lesson, disappeared again for six lessons, and then appeared in the context of adding and subtracting fractions with unlike denominators. Two exposures over the course of 15 lessons are not sufficient for even students of average ability to acquire and retain a concept. The research-based curriculum introduced this skill and gave students practice in eight consecutive lessons. Then, in the very next lesson, students applied the skill in problems with unlike denominators.

Summing Up

Developing skills for learning and remembering are important goals for schools. The conundrum of how to respond to individual differences in learning and remembering has haunted educators for decades. As new theories from other disciplines make their way into education, they often play a part in the evolution of various educational responses to the challenge of individual differences in learning. Gerald Edelman's work on the overarching capacity of the human brain to categorize in connected ways has direct implications for educators.

This capacity to categorize may also be a key to understanding individual differences. Bright, intuitive learners may be capable of categorizing rapidly and flexibly, without the need for an instructional environment that emphasizes important samenesses and “warns” about unintended ones. These students can “figure out” important samenesses without getting seriously misled.

Consider the following example of teaching students to rewrite fractions. It begins with such semiconcrete representations as this:

$$\begin{array}{c} \text{○} \\ \text{—} \\ \text{—} \\ \text{—} \\ \text{—} \\ \text{○} \end{array} \quad \frac{1}{4} \quad = \quad \frac{?}{8} \quad \begin{array}{c} \text{○} \\ \text{—} \\ \text{—} \\ \text{—} \\ \text{—} \\ \text{—} \\ \text{—} \\ \text{—} \\ \text{○} \end{array}$$

The pictures are assumed to develop the concept that $1/4$ can also be written as $2/8$, because the same area of both circles is shaded. The inappropriate sameness implied by problems of this type is that the answer can be determined by counting the shaded parts, ignoring everything else. This misconception can easily be demonstrated by asking students to solve a problem such as $2/3 = ?/6$. There are no shaded parts to count.

The intuitive learner, left without parts to count, will look for other samenesses that will yield an answer, a process similar to deducing that Zug does not mean subtract. Knowing when to search for new samenesses, how to generate alternative samenesses, and how to evaluate those samenesses are the hallmarks of the intuitive learner.

The challenge for educators is quite different with low-achieving students. One problem is to help those students become more “intuitive.” Yet designing activities toward that end must not be the only tactic, partly because documented successes in creating such activities for low-achieving students are rare. The other tactic was illustrated above: designing a learning environment to maximize the likelihood that students will learn important samenesses. For example, in teaching low-achieving students to rewrite fractions, one important sameness can be expressed as a rule: “Multiplying one side of an equation by 1 or by a fraction equal to 1 does not change the value of that side.” Thus, when students are asked to rewrite $\frac{2}{3}$ as a fraction with 15 in the denominator, they will understand that they must multiply $\frac{2}{3}$ by a fraction that is equivalent to 1 and that will convert the 3 in the denominator to a 15. Thus their choice must be $\frac{5}{5}$. The rule about multiplying by 1 derives from one of the great unifying principles of mathematics: identity elements for mathematical operations do not alter relationships.

A different type of equality underlies the interest of educators in individual differences—not equal treatment, not even equal outcomes, but equal opportunity to learn and flourish in school. Determining the nature of those opportunities is education’s grail. Differing theories of the brain can be interpreted as supporting different instructional approaches, and choices among

these approaches should be based as much as possible on their effects on students.

This seeming truism is actually very difficult to put into practice.(20) For example, the notion that individual learning styles stem from relative strengths and weaknesses of brain functions was very popular in special education in the 1960s and 1970s. However, numerous research studies documented seemingly insurmountable flaws in the way in which special education applied that notion.(21) Among these flaws are the following: 1) measures for identifying students' learning styles are not reliable (e.g., a student might exhibit a visual strength on the day of testing but a visual weakness on a different day); 2) relationships between learning-style strengths and academic performance are weak (e.g., the correlation between students' scores on tests of learning styles and their scores on reading tests was lower than the correlation between students' scores on reading tests and their scores on tests of math computation); and 3) instruction matched to students' learning styles had relatively weak effects on academic performance (e.g., instruction to improve visual functioning didn't appreciably improve reading performance). As noted in a recent *Kappan* article, the research base on learning styles outside of special education is also open to question.(22)

On the other hand, the educational principles outlined in this article have been subjected to large-scale evaluations in elementary reading and mathematics.(23) Small-scale research studies at the University of Oregon have also been conducted in various secondary subjects, including physical science, law, critical reading, syllogistic reasoning, math word problems, problem solving, and literary analysis.(24) The point I wish to leave with readers is that arguing by analogy from brain research to education provides

only a rationale for an approach. The actual effect of the approach on students is what is crucial. Edelman's new research on the brain provides a strong rationale for the analysis of sameness, which has extensive research support.

Douglas Carnine is a professor in the College of Education at the University of Oregon, Eugene. ©1990. Douglas Carnine.

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Notes

- (1) Marie Carbo, "Reading Styles Research: 'What Works' Isn't Always Phonics," *Phi Delta Kappan*, February 1987, pp. 431-35.
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Survey of Research on Learning Styles

by Rita Dunn, Jeffrey S. Beaudry, and Angela Klavas

A number of studies conducted during the last decade have found that students' achievement increases when teaching methods match their learning styles—biological and developmental characteristics that affect how they learn.

Research on learning styles has been conducted at more than 60 universities over the past decade. These investigations have yielded useful findings about the effects of environmental, emotional, sociological, physiological, and cognitive preferences on the achievement of students. Learning style is a biologically and developmentally imposed set of personal characteristics that make the same teaching method effective for some and ineffective for others.

Every person has a learning style—it's as individual as a signature. Knowing students' learning styles, we can organize classrooms to respond to their individual needs for quiet or sound, bright or soft illumination, warm or cool room temperatures, seating arrangements, mobility, or grouping preferences. We can recognize the patterns in which people tend to concentrate

best—alone, with others, with certain types of teachers, or in a combination thereof. We become aware of the senses through which people remember difficult information most easily—by hearing, speaking, seeing, manipulating, writing or notetaking, experiencing, or, again, a combination of these. Learning style also encompasses motivation, on-task persistence versus the need for multiple assignments simultaneously, the kind and amount of structure required, and conformity versus nonconformity. When a National Association of Secondary School Principals (NASSP) Task Force (1983) examined all the characteristics that influence student achievement, intake preferences (individual needs for eating and/or drinking while concentrating) achieved the highest reliability. Chronobiology is also part of style: some people are “morning people”; some are “night owls.”

There are only three comprehensive models of learning style (Hill et al. 1971, Keefe et al. 1986, Dunn et al. 1975, 1979, 1981, 1985); others address only one to four elements, usually on a bipolar continuum. Although various scholars define the concept differently, only a few learning style identification instruments are reliable and valid (Curry 1987).

Correlational Studies

To investigate connections between individual preferences and other influences on learning, researchers have conducted correlational studies to establish the relationships between learning style and birth order, cognitive development, maturation, hemisphericity, field dependence/independence, global/analytic processing, temperament, and self-concept. Their comparisons examined learners at all levels from primary school through adulthood. They differentiated among gifted, musically and artistically talented, average, underachieving, at-risk, nontraditional,

reading-disabled, special education, dropout, and adolescent psychiatric populations. Researchers further tested consistency of style over subject matter and time. In addition, the researchers determined the responsiveness of basal readers to style differences, and they also examined the extent to which teacher training programs complemented their student candidates.

Correlational studies also explored the similarities and differences between and among diverse groups. Thus, researchers developed profiles of the styles of a wide range of learners, including students at various levels of achievement in diverse age groups; gifted, learning disabled, and mentally retarded students; supervisors and their supervisees; teachers and their students; Southeast Asian and American Caucasian college registrants; and numerous other groups. In addition, comparisons were made of the learning styles of Bahamians and Jamaicans; Afro-Americans and Caucasians; and Afro-, Chinese, Greek, and Mexican Americans (*Annotated Bibliography* 1988; *Learning Styles Network Newsletter* 1980-1988).

Correlations Between Learning Style and Hemisphericity

As new findings about left/right brain functions appeared, researchers investigated the connections between learning style and hemisphericity. The terms *left/right*, *analytic/global*, and *inductive/deductive* have been used interchangeably in the literature; descriptions of these pairs of variables parallel each other. Lefts/analytics/inductives appear to learn successively, in small steps leading to understanding; rights/globals/deductives more easily learn by obtaining meaning from a broad concept and then focusing on details.

Studies that examined the similarities and differences between hemispheric style and other elements of learning style revealed

that, when concentrating on difficult academic material:

- 1) High school students who were less motivated than their classmates and who preferred working with *distracters* (music, low illumination, informal or casual seating, peers rather than alone or with the teacher, tactile rather than auditory or visual instructional resources) scored right-hemisphere significantly more often than left-hemisphere. Also, students who scored high on persistence invariably scored high as left processors (Dunn et al. 1982). (The latter data may have implications for time-on-task research.)
- 2) Left-hemisphere youngsters in grades 5-12 preferred a conventional formal classroom seating design, more structure, less intake, and visual rather than tactile or kinesthetic resources during learning significantly more often than their right-preferenced classmates (Cody 1983).
- 3) Right-hemisphere 5th through 12th graders disliked structure and were not adult motivated but *were* strongly peer motivated. Gifted and highly gifted students were significantly more often right or integrated than left processors (Cody 1983).
4. Right-hemisphere community college adult math under-achievers preferred learning with sound and intake. They wanted tactile and kinesthetic instructional resources and mobility significantly more often than their left-hemisphere counterparts, who preferred bright light and a formal design. [When the predominantly right-hemisphere students were taught alternately with both global and analytic lessons, they achieved statistically higher test scores through the global, rather than through the analytic, resources (Bruno 1988).]

Thus, correlational studies revealed sets of traits among students within the same age or grade and among those with similar talents, achievement, and interests. Even when culturally diverse

groups were examined, there were as many within-group as between-group differences. Within each family, the parents, their offspring, and the siblings tend to be more different from than similar to each other.

Figure 1. Experimental Research Concerned with Learning Styles and Instructional Environments

RESEARCHER/ DATE	SAMPLE	SUBJECT EXAMINED	ELEMENT EXAMINED	SIGNIFICANT ACHIEVEMENT	EFFECTS ATTITUDES
DeGregoris 1986	6th, 7th, 8th graders	Reading comprehension	Kinds of sounds needed by sound preferences	+ With moder- ate talking	Not tested
DellaValle 1984	7th graders	Word recogni- tion memory	Mobility/ passivity needs	+	Not tested
Hodges 1985	7th, 8th graders	Mathematics	Formal/infor- mal design preferences	+	+
Krimsky 1982	4th graders	Reading speed and accuracy	Bright/low lighting preferences	+	Not tested
MacMurren 1985	6th graders	Reading speed and accuracy	Need for intake while learning	+	+
Miller 1985	2nd graders	Reading	Mobility/pas- sivity needs	+	Not tested
Murray 1983	7th graders	Word recogni- tion memory	Temperature preferences	0	Not tested
Pizzo	6th graders	Reading	Acoustical preferences	+	+
Shea 1983	9th graders	Reading	Formal/infor- mal design preferences	+	Not tested
Stiles 1985	5th graders	Mathematics testing	Formal/infor- mal design preferences	0	Not tested

Note: Price (1980) reported that the older students became, the less they appeared able to adapt to a conventional setting. Thus, design may be far more crucial to secondary students' ability to concentrate than to 4th graders, who may be better able to adjust to this element. Dunn.

(+) = significant positive findings at $p < .01$ or greater, (0) = no differences or slight trend.

Experimental Research

These correlational findings prompted researchers to conduct experimental studies to determine the effects of individual learning style on achievement, attitudes, and/or behavior.

On Instructional Environments

The extent to which classrooms appear either to stimulate or to inhibit learning for students with selected learning style characteristics has been documented in terms of individuals' needs for quiet versus sound, bright or soft lighting, warm or cool temperatures, and formal versus informal seating designs (Dunn 1987, Dunn et al. 1985; see fig. 1). These four elements affect from 10 to 40 percent of students, dependent upon age, gender, hemisphericity, and achievement. For example, the need for sound remains fairly consistent during the elementary school years but increases as adolescence begins and, as that stage passes, appears to return to its previously normal level. The younger children are, the less light they need; but about every five years most children require significantly more light than previously. Boys tend to require more mobility than girls and, thus, find sitting for any length of time difficult (Price 1980). However, teachers often view negatively the children who squirm in their seats, tap their pencils, complain about the temperature, or become hyperactive (in some cases because of too much illumination).

On Perceptual Preferences

In addition to the instructional environment, sensory preferences influence the ways in which students learn. Eight studies within the past decade reveal that when youngsters were taught with instructional resources that both matched and mismatched their preferred modalities, they achieved statistically higher test

scores in modality-matched, rather than mismatched, treatments (Dunn 1988; see fig. 2). In addition, when children were taught with multisensory resources, but *initially through their most preferred modality* and then were reinforced through their secondary or tertiary modality, their scores increased even more.

Perceptual preferences affect more than 70 percent of school-age youngsters. High school teachers who have translated their curriculum into electroboards, Flip chutes, multipart task cards, and Pick-A-Holes reported increased achievement and interest when such manipulatives were available for highly tactual students (Dunn and Griggs 1988).

Data from studies conducted before the late '70s concerned with perceptual strengths often were conflicting because of inappropriate statistical design, poor analyses, misinterpretations of the findings, and/or faulty conclusions. Those investigators examined *group* mean gain scores—which are inappropriate for determining whether individuals achieve better, the same, or less well in comparison with their own baseline data when they are taught through their preferences. In addition, the words *tactile* and *kinesthetic* often were used interchangeably. *Tactile* suggests learning with hands through manipulation of resources, but writing is not tactile enough for children below 4th grade. *Kinesthetic* implies whole-body involvement, such as taking a trip, dramatizing, interviewing, or pantomiming. However, even when older studies identified tactile strengths, their treatments did not *introduce* the new material that way. Finally, studies that employed many diverse instruments, populations, methods, and statistical designs and that confused the terminology could not yield solid data.

On Sociological Preferences

The influence of students' social preferences also affects their achievement in school. In four of five studies, when students' sociological preferences were identified and the youngsters then were taught in multiple treatments both responsive and unresponsive to their diagnosed learning styles, they achieved significantly higher test scores in matched conditions and significantly lower test scores when mismatched.

How do sociological preferences interface with cooperative learning? The higher the grade level, the less teacher-motivated students become (Price 1980). Thus, there are more peer-oriented youngsters able to work in well-organized small groups than there are students willing to learn directly from their teachers. Nevertheless, in every class we have ever tested, there are students who prefer to learn by themselves with appropriate resources, others who prefer to learn with peers, and some who wish to work directly with their teachers (Price 1980).

From practical experience, educators generally consider the junior high school years a period of strong peer influence. By the beginning of grade 9, however, educators should expect movement away from that preference; Price (1980) found that students in grades 9-12 experience a greater need to learn and study alone than during any other interval. The gifted also prefer to learn alone unless the material to be mastered is difficult for them; when that happens, they prefer to learn with other gifted children. Thus, except among the gifted, many students in grades 3-8 will learn better in small, well-organized groups than either alone or with the teacher. After grade 8, however, more will learn better alone.

In a small group structure, children who are frequently chastised for not sitting quietly can move about and relieve the

discomfort they experience because of mobility needs or hard chairs. This structure also permits youngsters to read together, discuss items, reason out answers, and use multisensory interactions. The various contributors may enjoy different processing styles; thus, they can help each other, especially when the teacher’s dominant hemispheric style is incongruent with theirs. Despite the advantages to group work, students who feel constrained by the slower group pacing or who enjoy the challenge of solving problems by themselves do not learn most easily through small-group instructional strategies, nor do they enjoy the experience.

Figure 2. Experimental Research Concerned with Perceptual Learning Styles

RESEARCHER/ DATE	SAMPLE	SUBJECT EXAMINED	PERCEPTUAL PREFERENCE EXAMINED	SIGNIFICANT ACHIEVEMENT	EFFECTS ATTITUDES
Carbo 1980	Kindergartners	Vocabulary	Auditory, visual "other" (tactile)	+	Not tested
Jarsonbeck 1984	4th grade under- achievers	Mathematics	Auditory, visual, tactile	+	Not tested
Kroon 1985	9th, 10th graders	Industrial Arts	Auditory, visual, tactile, sequenced	+	Not tested
Martini 1986	7th graders	Science	Auditory, visual, tactile	+	+
Urbschat 1977	1st graders	CVC Trigram Recall	Auditory, visual	+	Not tested
Weinberg 1983	3rd graders	Mathematics	Auditory, visual, tactile	+	Not tested
Wheeler 1980	Learning disabled 2nd graders	Reading	Auditory, visual, tactile, sequenced	+	Not tested
Wheeler 1983	Learning disabled 2nd graders	Reading	Auditory, visual, tactile	+	Not tested

(+) = significant positive findings.

Research on Time-of-Day Preferences

It is common knowledge that morning people and night owls function better at their respective times of day. The research supports our easy acceptance of these preferences. For example, two junior high school principals revealed that the math underachievers in both their schools preferred learning in the afternoon but had been scheduled into morning math classes. When those youngsters were rescheduled into afternoon classes, they evidenced higher motivation, better discipline, and an increase in achievement. Three years later, a New York high school reported that time preference was a crucial factor in the reversal of initial and chronic truancy patterns among secondary students (Dunn et al. 1987). Similar data were reported by the director of five alternative high schools in Washington (Dunn and Griggs 1988).

In 1983, the matching of elementary students' time preferences with their instructional schedules resulted in significant achievement gains in both reading and math over a two-year period. One year later, *teachers'* time preferences were identified, and staff development was conducted during their preferred and nonpreferred times (early morning and immediately after school). Interestingly, those teachers implemented innovative instructional techniques significantly more often (as reported by their supervisors' evaluations) when *they* were taught during their most preferred hours. Then an elementary school principal in Kansas administered the *Iowa Basic Skills Tests* in reading and math to groups whose time preferences matched their test schedules—either early morning or afternoon. She reported significantly higher test gains in both subjects as compared with each youngster's previous two years' growth (Dunn et al. 1987).

Studies of dropouts, underachievers, at-risk (Griggs and Dunn 1988), and vocational education (Tappenden 1983) students indicate that, as a group, they are *not* morning people; neither were the truants in the New York experiment. For each of these groups, learning in late morning, afternoon, or evening significantly increased achievement.

Among the more interesting findings of research with time preferences is that most students are not morning-alert. At the elementary school level, approximately 28 percent appear to be “early birds”; many do not begin to be capable of concentrating on difficult material until after 10:00 a.m., and many are at their best in the early afternoon. Only about one-third of more than a million students we have tested prefer learning in the early morning, and the majority prefer late morning or afternoon. At the high school level, almost 40 percent are early morning learners, but a majority remain most alert in the late morning and afternoon; and, for the first time identifiable after early childhood, almost 13 percent are “night owls,” able to concentrate on difficult material in the evening (Price 1980). However, most teachers are early morning, high-energy people but often experience lows after 1:00 p.m. Another large group of educators merely get by much of the day and become mentally alert toward evening.

Mobility Needs

One element of learning style is the need for physical activity, and a review of this research reveals how this need can be confused with other, more alarming diagnoses. For example, Fadley and Hosler (1979) noted that children often were referred to psychologists because of their consistent hyperactivity; their teachers complained that such youngsters were unable to sit quietly and pay attention during lessons. Those psychologists

reported that most students sent to them were not at all clinically hyperactive; instead, they were normal children in need of movement. In addition, the less interested they were in the lesson, the more mobility the children required.

During the same period, Restak (1979) substantiated that “over 95 percent of hyperactives are males” (p. 230) and that the very same characteristic, when observed in girls, correlated with academic *achievement*. He deplored that boys were required to be passive in school and were rejected for aggressive behaviors there, but were encouraged societally to engage in typical male aggressions in the world at large; this paradox could lead to role conflict. Restak added that conventional classroom environments did not provide male students with sufficient outlets for their normal needs. He warned that schools actually *caused* conflict with societal expectations that boys not be timid, passive, or conforming.

Other researchers corroborated Restak’s admonitions and chastised educators for believing that physical activities prevented, rather than enhanced, learning. Indeed, when previously restless youngsters were reassigned to classes that did not require passivity, their behaviors were rarely noticed. Eventually, teachers began to report that although certain students thrived in activity-oriented environments that permitted mobility, others remained almost exclusively in the same area despite frequent attempts to coax them to move (Dunn et al. 1986). That led to Fitt’s (1975) conclusions that no amount of persuasion increased certain children’s interest in movement, whereas others found it impossible to remain seated passively for extended periods. “These are cases of a child’s style . . . governing his interaction with and within the environment” (p. 94).

DellaValle's (1984) research documented that almost half the 7th graders in a large urban racially mixed but predominantly black junior high school could not sit still for any length of time. Twenty-five percent could but only when interested in the lesson, and the remaining 25 percent *preferred* passivity. When preference and environment were matched, students' performance yielded significantly higher test scores than when they were mismatched.

Everyone Has One

Every person has a learning style—all have at least some preferences—the result of many influences. Certain learning style characteristics are biological, whereas others are developed through experience (Restak 1979, Thies 1979). Individual responses to sound, light, temperature, design, perception, intake, chronobiological highs and lows, mobility needs, and persistence appear to be biological; whereas sociological preferences, motivation, responsibility (conformity), the need for structure are thought to be developmental. The significant differences among diverse cultures tend to support this theory (*Learning Styles Network Newsletter* 1980-1988). Despite cultural influences, however, within each culture, socioeconomic strata, and classroom *there are as many within-group differences as between-group differences*. Indeed, each *family* includes parents and offspring with styles that differ.

Those who suggest that children should learn to adapt to their teachers' styles disregard the biological nature of style. They also disregard Cafferty's (1980) findings that the closer the match between each student's and the teachers' styles, the higher the grade point average; and the reverse. In addition, Kagan (1966) reported that his "success" with training impulsive students to become more reflective was evidenced only when adults

were present. In addition, although Kagan's subjects learned to respond more reflectively, *their accuracy on tasks was decreased*. Thus, educators can see that learning styles are not lightly held; they demonstrate remarkable resistance to change.

Identifying learning styles as a basis for providing responsive instruction has never been more important than now, as educators meet the needs of a diverse student population. To identify their students' learning styles (Beaty 1986, Dunn et al. 1977, Marcus 1977), teachers must use a reliable and valid learning style preference instrument (Curry 1987). When permitted to learn difficult academic information or skills through their identified preferences, children tend to achieve statistically higher test and attitude scores than when instruction is dissonant with their preferences.

No learning style is either better or worse than another. Since each style has similar intelligence ranges, a student cannot be labeled or stigmatized by having any type of style. Most children can master the same content; *how* they master it is determined by their individual styles.

(1) When we use the terms *significant* and *significantly*, we mean in a statistical sense.

Rita Dunn is Professor, Division of Administrative and Instructional Leadership, and Director, Center for the Study of Learning and Teaching Styles; Jeffrey S. Beaudry is Assistant Professor, Division of Administrative and Instructional Leadership; and Angela Klavas is Assistant Director, Center for the Study of Learning and Teaching Styles, and a doctoral student in the Instructional Leadership Program—all at St. John's University, Grand Central and Utopia Parkways, Jamaica, NY 11439.

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What Does It Mean to Be Smart?

by Robert J. Sternberg

A Yale study, based on the premise that intelligence has analytical, creative, and practical aspects, shows that if schools start valuing all three, they may find that thousands of kids are smarter than they think.

The most widely circulated newspaper in Connecticut recently carried a story on the meteoric rise of the president of one of the major banks in the state. I might have passed over the story with a glance had the name of the bank president not caught my eye. He was someone with whom I had gone to school from 1st grade right up through high school. What especially caught my attention, though, was that he had been a C student—someone who didn't seem to have much to offer.

Were the bank president an isolated case it might not be cause for alarm. But one cannot help wondering how many such students conclude that they really do not have much to contribute—in school or in the world at large—and so never try.

The Cost of a Closed System

Our system of education is, to a large degree, a closed system. Students are tested and classified in terms of two kinds of abilities—their ability to memorize information and, to a lesser extent, their ability to analyze it. They are also taught and assessed in ways that emphasize memory and analysis. As a result, we label students who excel in these patterns of ability as smart or able. We may label students who are weaker in these abilities as average or even slow or stupid.

Students may, however, excel in other abilities that are at least as important as those we now reward. Creativity and the practical application of information—ordinary common sense or “street smarts”—are two such abilities that go unappreciated and unrecognized. They are simply not considered relevant to conventional education.

The ability tests we currently use, whether to measure intelligence or achievement or to determine college admissions, also value memory and analytical abilities. These tests predict school performance reasonably well. They do so because they emphasize the same abilities that are emphasized in the classroom.

Thus, students who excel in memory and analytical abilities get good grades. Practically oriented learners, however, who are better able to learn a set of facts if they can see its relevance to their own lives, lose out. (Indeed, many teachers and administrators are themselves practical learners who simply tune out lectures or workshops they consider irrelevant to them.)

The consequences of this system are potentially devastating. Through grades and test scores, we may be rewarding only a fraction of the students who should be rewarded. Worse, we may be inadvertently disenfranchising multitudes of students from

learning. In fact, when researchers have examined the lives of enormously influential people, whether in creative domains (Gardner 1993), practical domains (Gardner 1995), or both, they have found that many of these people had been ordinary—or even mediocre—students.

Teaching in All Four Ways

At any grade level and in any subject, we can teach and assess in a way that enables students to use all four abilities (Sternberg 1994, Sternberg and Spear-Swerling 1996. See also Sternberg and Williams 1996, Williams et al. 1996). In other words, we can ask students to

- Recall who did something, what was done, when it was done, where it was done, or how it was done;
- Analyze, compare, evaluate, judge, or assess;
- Create, invent, imagine, suppose, or design; and
- Use, put into practice, implement, or show use.

In physical education, for example, competitors need to learn and remember various strategies for playing games, analyze their opponents' strategies, create their own strategies, and implement those strategies on the playing field. Figure 1 presents some examples of how teachers can do this in language arts, mathematics, social studies, and science.

When we use this framework, relatively few activities will end up requiring only one of these four abilities. On the contrary, most activities will be a mixture, as are the tasks we confront in everyday life. Notice that in this framework, instruction and assessment are closely related. Almost any activity that is used for the one can be used for the other.

Figure 1 **TEACHING FOR FOUR ABILITIES**

TYPE OF SKILL			
Memory	Analysis	Creativity	Practicality
LANGUAGE ARTS			
Remember what a gerund is or what the name of Tom Sawyer's aunt was.	Compare the function of a gerund to that of a participle, or compare the personality of Tom Sawyer to that of Huckleberry Finn.	Invent a sentence that effectively uses a gerund, or write a very short story with Tom Sawyer as a character.	Find gerunds in a newspaper or magazine article and describe how they are used, or say what general lesson about persuasion can be learned from Tom Sawyer's way of persuading his friends to white-wash Aunt Polly's fence.
MATHEMATICS			
Remember a mathematical formula (Distance = Rate x Time).	Solve a mathematical word problem (using the $D = RT$ formula).	Create your own mathematical word problem using the $D = RT$ formula.	Show how to use the $D = RT$ formula to estimate driving time from one city to another near you.
SOCIAL STUDIES			
Remember a list of factors that led up to the U.S. Civil War.	Compare, contrast, and evaluate the arguments of those who supported slavery versus those who opposed it.	Write a page of a journal from the view-point of a soldier fighting for one or the other side during the Civil War.	Discuss the applicability of lessons of the Civil War for countries today that have strong internal divisions, such as the former Yugoslavia.
SCIENCE			
Name the main bytypes of bacteria.	Analyze the means the immune system uses to fight bacterial infections.	Suggest ways to cope with the increasing immunity bacteria are showing to anti-biotic drugs.	Suggest three steps that individuals might take to reduce the likelihood of bacterial infection.

In addition, no type of activity should be limited to students whose strength is in that area. On the contrary, we should teach all students in all four ways. In that way, each student will find at least some aspects of the instruction and assessment to be compatible with his or her preferred way of learning and other aspects to be challenging, if perhaps somewhat uncomfortable.

Teaching in all four ways also makes the teacher's job easier and more manageable. No teacher can individualize instruction and assessment for each student in a large class, but any teacher can teach in a way that meets all students' needs.

Does This Work in Practice?

In the summer of 1993, we conducted a study of high school students to test our hypothesis that students learn and perform better when they are taught in a way that at least partially matches their own strengths (Sternberg 1996; Sternberg and Clinkenbeard 1995; Sternberg et al. 1996). Known as the Yale Summer Psychology Program, the study involved 199 students from high schools across the United States and some from abroad.

Each school had nominated students for the program. Interested nominees then took a test designed to measure their analytical, creative, and practical abilities. The test included multiple-choice verbal, quantitative, and figural items, as well as analytical, creative, and practical essay items (Sternberg 1993). A sample of the items appears in Figure 2.

We then selected the students who fit into one of five ability patterns: high analytical, high creative, high practical, high balanced (high in all three abilities), or low balanced (low in all three abilities). We based these judgments on both the individual student's patterns and the way these patterns compared to those of the other students.

Figure 2

SAMPLE MULTIPLE-CHOICE QUESTIONS FROM THE STERNBERG TRIARCHIC ABILITIES TEST	
ANALYTICAL VERBAL	<p>The vip was green, so I started to cross the street. <i>Vip</i> likely means:</p> <p>A. car C. light B. sign D. tree</p>
CREATIVE QUANTITATIVE	<p>There is a new mathematical operation called graf. It is defined as follows: $x \text{ graf } y = x + y$, if $x < y$ but $x \text{ graf } y = x - y$, if otherwise.</p> <p>How much is 4 graf 7?</p> <p>A. -3 C. 11 B. 3 D. -11</p>
PRACTICAL FIGURAL (Students are shown a map)	<p>After attending a performance at the theater, you need to drive to House A. If you want to avoid the traffic jam at the intersection of Spruce Ave. and Willow St. and take the shortest alternative route, you will drive.</p> <p>A. west on Maple Ave. to Route 326. B. west on Pine St. to Hickory St. C. east on Maple Ave. to Oak St. D. east on Pine St. to Oak St.</p>

We then placed each student into one of four differentiated instructional treatments. All included a morning lecture that balanced memory, analysis, creativity, and practical learning and thinking. All students used the same introductory psychology text (Sternberg 1995), which was also balanced among the four types of learning and thinking. The treatments differed, however, in the afternoon discussion sections. There, we assigned students

to a section that emphasized either memory, analysis, creativity, or practical learning and thinking.

The critical feature of this design was that, based on their ability patterns, some students were matched and others mismatched to the instructional emphasis of their section. Another important feature was that all students received at least some instruction emphasizing each type of ability.

We assessed student achievement through homework assignments, tests, and an independent project. We assessed memory specifically through multiple-choice tests, and we evaluated analytical, creative, and practical abilities through essays. For the essays, we asked students questions such as “Discuss the advantages and disadvantages of having armed guards at school” (analysis); “Describe what your ideal school would be like” (creativity); and “Describe some problem you have been facing in your life and then give a practical solution” (practical use).

Because we assessed all students in exactly the same way, we could more easily compare the groups’ performance. Had we used the more conventional forms of instruction and assessment, emphasizing memory and analysis, the creative and practical ability tests would probably not have told us much.

Some Surprises

The study yielded many findings, but four stand out:

1. Students whose instruction matched their pattern of abilities performed significantly better than the others. Even by partially matching instruction to abilities, we could improve student achievement.
2. By measuring creative and practical abilities, we significantly improved our ability to predict course performance.

3. To our surprise, our four high-ability groups differed in their racial, ethnic, and socioeconomic composition. The high-analytic group was composed mostly of white, middle- to upper-middle-class students from well-known “good” schools. The high-creative and high-practical groups were much more diverse racially, ethnically, socioeconomically, and educationally. Our high-balanced group was in between. This pattern suggests that when we expand the range of abilities we test for, we also expand the range of students we identify as smart.

4. When we did a statistical analysis of the ability factors underlying performance on our ability test, we found no single general factor (sometimes called a g factor score or an IQ). This suggests that the general ability factor that has been found to underlie many conventional ability tests may not be truly general, but general only in the narrow range of abilities that conventional tests assess.

A Clear-Eyed Sense of Accomplishment

By exposing students to instruction emphasizing each type of ability, we enable them to capitalize on their strengths while developing and improving new skills. This approach is also important because students need to learn that the world cannot always provide them with activities that suit their preferences. At the same time, if students are never presented with activities that suit them, they will never experience a sense of success and accomplishment. As a result, they may tune out and never achieve their full potential.

On a personal note, I was primarily a creative learner in classes that were largely oriented toward memorizing information. When in college, I took an introductory psychology course that was so oriented; I got a C, leading my instructor to suggest that

I might want to consider another career path. What's more, that instructor was a psychologist who specialized in learning and memory! I might add that never once in my career have I had to memorize a book or lecture. But I have continually needed to think analytically, creatively, and practically in my teaching, writing, and research.

Success in today's job market often requires creativity, flexibility, and a readiness to see things in new ways. Furthermore, students who graduate with As but who cannot apply what they have learned may find themselves failing on the job.

Creativity, in particular, has become even more important over time, just as other abilities have become less valuable. For example, with the advent of computers and calculators, both penmanship and arithmetic skills have diminished in importance. Some standardized ability tests, such as the SAT, even allow students to use calculators. With the increasing availability of massive, rapid data-retrieval systems, the ability to memorize information will become even less important.

This is not to say that memory and analytical abilities are not important. Students need to learn and remember the core content of the curriculum, and they need to be able to analyze—to think critically about—the material. But the importance of these abilities should not be allowed to obfuscate what else is important.

In a pluralistic society, we cannot afford to have a monolithic conception of intelligence and schooling; it's simply a waste of talent. And, as I unexpectedly found in my study, it's no random waste. The more we teach and assess students based on a broader set of abilities, the more racially, ethnically, and socioeconomically diverse our achievers will be. We can easily change our closed system—and we should. We must take a more balanced

approach to education to reach all of our students.

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Robert J. Sternberg is a Professor in the Department of Psychology, Yale University, P.O. Box 208205, New Haven, CT 06520-8205 (e-mail: sterobj@yalevm.cis.yale.edu).

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