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BRAIN POWER

Studying Young Minds, and How to Teach Them

By BENEDICT CAREY

BUFFALO — Many 4-year-olds cannot count up to their own age when they arrive at preschool, and those at the Stanley M. Makowski Early Childhood Center are hardly prodigies. Most live in this city's poorer districts and begin their academic life well behind the curve.

But there they were on a recent Wednesday morning, three months into the school year, counting up to seven and higher, even doing some elementary addition and subtraction. At recess, one boy, Joshua, used a pointer to illustrate a math concept known as cardinality, by completing place settings on a whiteboard.

"You just put one plate there, and one there, and one here," he explained, stepping aside as two other students ambled by, one wearing a pair of clown pants as a headscarf. "That's it. See?"

For much of the last century, educators and many scientists believed that children could not learn math at all before the age of five, that their brains simply were not ready.

But recent research has turned that assumption on its head — that, and a host of other conventional wisdom about geometry, reading, language and self-control in class. The findings, mostly from a branch of research called cognitive neuroscience, are helping to clarify when young brains are best able to grasp fundamental concepts.

In one recent study, for instance, researchers found that most entering preschoolers could perform rudimentary division, by distributing candies among two or three play animals. In another, scientists found that the brain's ability to link letter combinations with sounds may not be fully developed until age 11 — much later than many have assumed.

The teaching of basic academic skills, until now largely the realm of tradition and guesswork, is giving way to approaches based on cognitive science. In several cities, including Boston, Washington and Nashville, schools have been experimenting with new curriculums to improve math skills in preschoolers. In others, teachers have used techniques developed by brain scientists to help children overcome dyslexia.

And schools in about a dozen states have begun to use a program intended to accelerate the development of young students' frontal lobes, improving self-control in class.

"Teaching is an ancient craft, and yet we really have had no idea how it affected the developing brain," said Kurt Fischer, director of the Mind, Brain and Education program at Harvard. "Well, that is beginning to change, and for the first time we are seeing the fields of brain science and education work together."

This relationship is new and still awkward, experts say, and there is more hyperbole than evidence surrounding many "brain-based" commercial products on the market. But there are others, like an early math program taught in Buffalo schools, that have a track record. If these and similar efforts find traction in schools, experts say, they could transform teaching from the bottom up — giving the ancient craft a modern scientific compass.

Beyond Counting

In a typical preschool class, children do very little math. They may practice counting, and occasionally look at books about numbers, but that is about it. Many classes devote mere minutes a day to math instruction or no time at all, recent studies have found — far less than most children can handle, and not nearly enough to prepare those who, deprived of math-related games at home, quickly fall behind in kindergarten.

“Once that happens, it can be very hard to catch up,” said Julie Sarama, a researcher in the graduate school of education at the University at Buffalo who, with her colleague and husband, Doug Clements, a professor in the same department, developed a program called Building Blocks to enrich early math education.

“They decide they’re no good at math — ‘I’m not a math person,’ they say — and pretty soon the school agrees, the parents agree,” Dr. Clements said.

“Everyone agrees.”

In a Building Blocks classroom, numbers are in artwork, on computer games and in lessons, sharing equal time with letters. Like “Sesame Street,” Building Blocks has children play creative counting games; but it also focuses on other number skills, including cardinality (how many objects are in a set) and one-to-one correspondence (matching groups of objects, like cups and saucers). Teachers can tailor the Building Block lesson to a student’s individual ability.

On a recent Wednesday afternoon at the Makowski center, Buffalo’s Public School 99, Pat Andzel asked her preschool class a question:

“How many did you count?”

She had drilled them on the number seven. She held up a sign with “7” and asked her students what number they saw (“seven!”); had the group jump seven times, counting; then had them touch their nose seven times. As the class finished counting seven objects on a poster, she asked again:

“How many?”

“I never used to ask that,” Ms. Andzel said in an interview after the lesson. She asks it all the time now, she said, because it drives home a subtle but crucial idea: that the last number they said in counting is the quantity; it is the answer.

“Many of these kids don’t understand that yet,” she said.

The curriculum includes a variety of math-based lessons and activities, as well as software programs, all drawing on findings from cognitive science. When it comes to understanding numbers, for example, recent research suggests that infants can distinguish one object from two, and two from three.

By preschool, the brain can handle larger numbers and is struggling to link three crucial concepts: physical quantities (seven marbles, seven inches) with abstract digit symbols (“7”), with the corresponding number words (“seven”). Lessons like the one Ms. Andzel taught are meant to fuse this numeric trinity, which is crucial for understanding basic math in kindergarten.

Children begin recognizing geometric shapes as early as 18 months, studies find; by preschool, the brain can begin to grasp informal geometric definitions.

It can when taught properly, that is. Many books use a pizza slice to illustrate a triangle, for example, even though slices are rounded at one end. Once a child has fused the word triangle with a specific shape (triangle = pizza slice), it is hard to break that association later on.

“The definition,” Dr. Clements said, “is a three-angled shape. Period.” Building Blocks teaches this definition, illustrating it with triangles skinny and fat, squat and tall.

In all, this curriculum and others link numbers to objects, to rhythms, to the chairs and plates around a table — to the physical world.

“If children have games and activities that demonstrate the relationship between numbers, then quantity becomes a physical experience,” said Sharon Griffin, a psychologist at Clark University in Worcester, Mass., who found in a series of careful studies that a curriculum she devised, called Number Worlds, raised the scores of children who lagged in math. “Counting, by contrast, is very abstract.”

In a study published last year, scientists at Carnegie Mellon University reported that playing what seems a simple childhood game, similar to Chutes and Ladders (sometimes called Snakes and Slides), accelerates the understanding of numbers for low-income preschoolers.

“Being told 8 is 2 times 4 is one thing,” said Robert S. Siegler, a psychologist who is one of the authors. “It’s another to see that it’s twice as far to the number 8, and that it takes twice as long to get there.”

The Number Instinct

“Use your eyes like cameras,” said Lara Lazo, one of the teachers at P.S. 99, after the midmorning break. “Get ready to take a snapshot.”

The children bracketed their eyes with their hands, making “cameras,” and Ms. Lazo showed them a paper plate with three dots on it — then quickly covered the plate.

“What number did you see?”

A cacophony of “threes” and “fours” erupted.

“O.K.,” she said. “Let’s try it again.”

The lesson is intended to teach a skill called subitizing. “The idea,” Dr. Sarama said, “is to get them to recognize quantity — to say, ‘I see three’ — not by counting, but by instantly recognizing how many are there by sight.”

A crude “number instinct” is hard-wired into the anatomy of the brain, recent research has found. Mammals can quickly recognize differences in quantity, choosing the tree or bush with the most fruit. Human beings, even if they live in remote cultures with no formal math education, have a general grasp of quantities as well, anthropologists have found.

In a series of recent imaging studies, scientists have discovered that a sliver of the parietal cortex, on the surface of the brain about an inch above the ears, is particularly active when the brain judges quantity. In this area, called the intraparietal sulcus, clusters of neurons are sensitive to the sight of specific quantities, research suggests. Some fire vigorously at the sight of five objects, for instance, less so at the sight of four or six, and not at all at two or nine. Others are most active in response to one, two, three, and so on.

When engaged in a lesson or exercise, these regions actively communicate with areas of the frontal lobe, where planning and critical thinking are centered.

“This is what we believe focused math education does: It sharpens the firing of these quantity neurons,” said Stanislas Dehaene, a cognitive neuroscientist at the Collège de France in Paris and author of the books “The Number Sense” and “Reading and the Brain.” The firing of the number neurons becomes increasingly more selective to single quantities, he said; and these cells apparently begin to communicate with neurons across the brain in language areas, connecting precise quantities to words: “two,” “ten,” “five.”

A similar honing process is thought to occur when young children begin to link letter shapes and their associated sounds. Cells in the visual cortex wired to recognize shapes specialize in recognizing letters; these cells communicate with neurons in the auditory cortex as the letters are associated with sounds.

The process may take longer to develop than many assume. A study published in March by neuroscientists at Maastricht University in the Netherlands suggested that the brain does not fully fuse letters and sounds until about age 11.

“As these kinds of findings come in, they will have implications not only for teaching, but also education policy,” said Daniel Ansari, an assistant professor in developmental cognitive neuroscience at Western Ontario University.

Explaining Five

In math, there is no faking it. Children either know that five is more than three, or they do not. Either they can put number symbols in exactly the right order, or they cannot. In their studies, Dr. Clements and Dr. Sarama test children one on one and videotape the results for comparisons.

Over the past four years, the couple has tested Building Blocks in more than 400 classrooms in Buffalo, Boston and Nashville, comparing the progress of children in the program with that of peers in classes offering another math curriculum or none at all. On tests of addition, subtraction and number recognition after one school year, children who had the program scored in the 76th percentile on average, and those who did not scored in the 50th percentile.

By the end of kindergarten, a year after the program has ended, those who had had it sustained their gains, scoring in the 71st percentile, on average.

Many hurdles remain for this and similar curriculums based in cognitive science, experts say. Schools may move away from the curriculum; teachers move around, as do students; and in later grades there is always the risk that children who have mastered basic math will not get the attention they need to advance even further.

But for now at least, education based on brain science has helped hundreds of Buffalo children refine their native abilities in math. In one videotaped exam, a 4-year-old boy in a FUBU jersey and long dreadlocks who entered P.S. 99 in 2006 was unable to count or match cards with 3, 5, 2, 1 and 4 on them to cards with equivalent numbers of grapes.

In a video of his post-Building Blocks exam, six months later, he instantly says there are 10 pennies placed in front of him, without counting. He easily matches the number cards to their corresponding grape cards — and puts the mixed-up numerals in the correct order.

“What’s the biggest, nine or seven or five?” asks the teacher giving the exam.

The boy thinks for a moment. “Nine,” he says. “Five is the littlest.” Then he holds one palm above the other and says: “Five is like this. See?”

“Do you see what he’s doing?” Dr. Clements said, interrupting the video. “Right there. He wants to explain. He wants to explain five.”