sent it at a meeting, say that Ogura's team used electroporation to misexpress the *Tbx4* and *Tbx5* genes in the developing wings and legs. And they got almost complete transformation from both hindlimb to wing and wing to hindlimb. These more dramatic results may be due to interactions between the proteins that are not yet understood, or to the electroporation method Ogura used to insert the new gene, which triggers gene expression in 2 to 3 hours instead of 12.

These genes may shape arms and legs in all vertebrates; scientists have already identified human equivalents of both *Tbx4* and *Tbx5*. A rare disorder called Holt-Oram syndrome, which causes severely shortened arms and heart defects, has been traced to defects in the human *TBX5* gene. Versions of the genes are also present in the newt, and scientists are searching for the zebrafish versions, hoping for clues to the genes' evolutionary history.

Based on other work on developmental signals, the researchers suspect that *Pitx1*, *Tbx4*, and *Tbx5* influence "wingness" or "legness" by altering a cell's response to similar growth factors. The difference between legs and wings could be due to subtle variations in when and where the common growth factors are active, leading to minor changes in the growth of analogous sets of bones in the two limbs, researchers say. "You have all the same cell types, but a slightly different pattern" in the different limbs, says Tabin. "And these genes turn out to be the heart of that difference."

The next step, says Logan, is to figure out how the limb-specifying genes fit into the hierarchy of signals that build arms and legs. For example, although *Pitx1* seems to turn on *Tbx4*, no equivalent gene has been found to direct *Tbx5* expression. And scientists are eager to discover exactly which growth factors and other genes *Tbx4* and *Tbx5* help to control. "It's a very complicated story," says Rosenfeld, "one that's not solved at all."

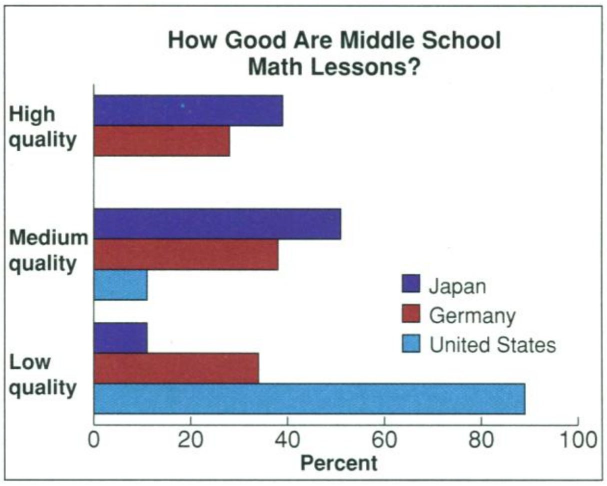
–GRETCHEN VOGEL

MATH EDUCATION

Videotapes Expose Classroom Faults

Test scores have documented how poorly many U.S. students do in math compared to their counterparts around the world. But why are their scores so low? A new analysis* just released by the U.S. Department of Education suggests that what happens in the classroom—what students are asked to do and how the material is taught—could provide at least part of the answer. And the data are in living color rather than being buried in answer sheets or questionnaires.

In 1994–95 researchers videotaped 231 eighth-grade mathematics classes in the United States, Japan, and Germany as part of the Third International Mathematics and Science Study (TIMSS). Conceived as an interesting sidelight to the main event—international tests of student achievement among fourth graders, eighth graders, and students in the last year of secondary school—the tapes have become one of the most informative and influential parts of TIMSS. Although confidentiality agreements prevent most of the tapes from being shown publicly, educators who have watched excerpts of a few that have been released and shown at conferences and workshops say they are shocked at the shortcomings of U.S. pedagogy. "I've seen teachers with tears of admiration in their eyes after watching some of the lessons from other countries," says one researcher who has analyzed them. "It's amazing to see a lesson play out so well."



Poor grades. The quality of the math taught in U.S. middle schools, judged by such measures as complexity and the use of deductive reasoning, is markedly lower than in Japan and Germany.

The tapes highlight teaching methods long suspected of pulling down U.S. achievement levels. "What the videotapes show—for example, that U.S. teachers cover more topics in a class than do teachers in other countries—is very consistent with earlier findings about the U.S. curriculum," says William Schmidt of Michigan State University in East Lansing, the national coordinator for U.S. TIMSS research. "And common sense says that the characteristics of the curriculum are going to have an effect on student achievement."

The classrooms videotaped were chosen at random from the pool of those that participated in TIMSS. A single lesson in each classroom was videotaped, and the video was then digitized, translated, transcribed, and put on a CD. Six coders, two from each country, watched the lessons and quantitatively analyzed the mathematics presented and the actions of students and teacher. In addition, a group of experienced college mathematics teachers read transcripts and judged the quality of each lesson after the source was disguised.

Perhaps the most distressing finding from the educators was the subpar mathematical content of the U.S. classes (see graphic). "Any particular indicator of quality might be questioned," says James Hiebert of the University of Delaware, Newark, a contributor to the study. "But no matter what indicator was used, most people agreed that the quality of the lessons was lower." Also, U.S. students typically were taught subjects one to two grades below those taught to their peers in Germany and Japan.

Teaching practices were remarkably uniform within each country, but they differed sharply from nation to nation. In Japan, teachers usually present their students with a problem and then let them work on it individually and in small groups so that students have to struggle with the relevant mathematical concepts. In the United States and Germany, teachers tend to drill students on concepts they have just described. The result, says the principal investigator for the study, James Stigler of the University of California, Los Angeles, is that "American and German students tend to practice routine procedures, while Japanese students are doing proofs."

Most of the teachers videotaped said that they had implemented practices from the standards issued by the National Council of Teachers of Mathematics (NCTM), which break the mold of traditional U.S. math classes by emphasizing high-level problem solving and greater flexibility in attacking a problem. But the tapes show little evidence of such innovations. "At the policy-making level, states and districts have been very influenced by the standards," says Glenda Lappan of Michigan State, the current NCTM president. "But there aren't many places where teachers [are encouraged] to move forcefully toward the standards."

However, Stigler and Hiebert say that teachers should not shoulder all the blame for the poor performance of U.S. students. "Teachers have been encouraged to teach the way they do," they write in a forthcoming book.† "They have been provided no

* The TIMSS Videotape Classroom Study, available at nces.ed.gov/timss

† *The Teaching Gap*, by James Stigler and James Hiebert, to be published in August by Free Press.

SOURCE: TIMSS VIDEOTAPE CLASSROOM STUDY

system in which they might spend time and energy studying and improving teaching."

Stigler and Hiebert also caution against interpreting the video findings too broadly. Japan's high scores on TIMSS might derive from other factors, they say, including extensive preparation for high school entrance exams. And German students did roughly the same as U.S. students on the TIMSS tests despite differences in pedagogy. "This is a study with a sample size of just three countries," says Stigler. "We should be careful not to say that particular teaching practices produce high student learning."

But educators are hoping to draw exactly those types of conclusions from a much larger project already under way. Stigler's research team and collaborators in six other countries are videotaping hundreds of eighth-grade math and science classes. The results, due out in 2001, are likely to produce more painful introspection for U.S. educators.

–STEVE OLSON

Steve Olson writes from Washington, D.C.

NEUROBIOLOGY

Memory for Order Found In the Motor Cortex

Every time we kick a ball, shake a hand, or spoon ice cream to our lips, we rely on a strip of tissue on the top of the brain known as the motor cortex to tell our muscles what to do. Now it appears that the motor cortex can do far more than simply orchestrate movements. On page 1752, a team led by neuroscientist Apostolos Georgopoulos of the University of Minnesota in Minneapolis and the Veterans Affairs Medical Center there reports that neurons in the motor cortex can also do a kind of thinking: They can help recognize and remember the sequence of events in time, at least as a prelude to movement.

If the findings hold up, researchers may have to rethink their view of the motor cortex, and perhaps of other brain regions, too, says Steven Wise, a neuroscientist at the National Institute of Mental Health (NIMH) in Poolesville, Maryland. The work, which Wise describes as "unprecedented," may mean, he says, "that the information needed to perform complex cognitive tasks is distributed very widely" in the brain. In that event, prospects for recovering from brain injuries may someday be brighter. If healthy areas share some functions of the damaged brain areas, Wise speculates, clinicians may be able to boost those functions and stimulate more complete recovery.

The new findings extend more than 2 decades of experiments indicating that in certain circumstances neurons in the motor cortex are active even when an animal isn't moving. In 1976, for example, Jun Tanji and Ed Evarts, then at NIMH, found activity in this region when an animal was preparing to move but not yet moving. And in the 1980s and early 1990s, Georgopoulos's team found that neuronal activity in the motor cortex can provide information about the direction of an upcoming movement and can also serve as a memory for the spatial locations of individual stimuli to which the animal was supposed to move.

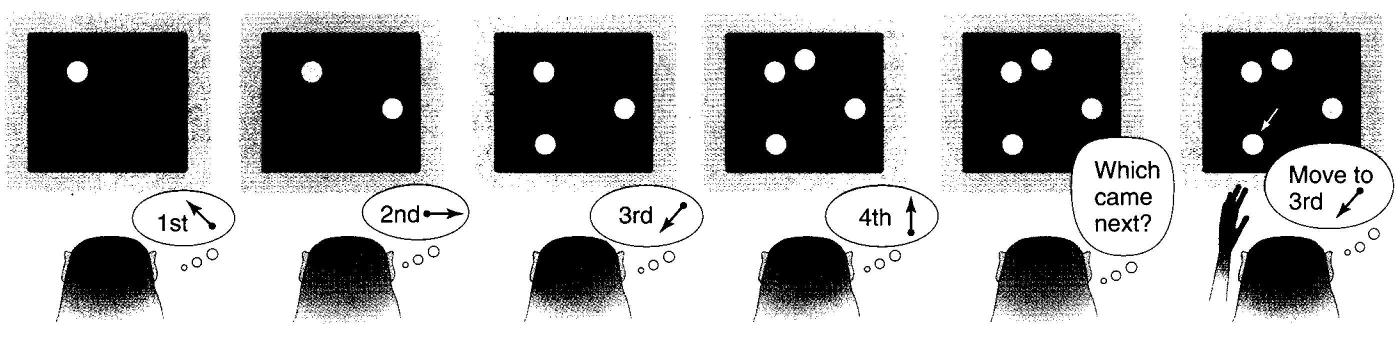
> **"What is truly impressive is the magnitude and robustness of the effect."**
>
> —Patricia Goldman-Rakic

Georgopoulos then wondered whether motor cortex cells also could keep track of several spatial locations when they are presented in a sequence. So in 1993, with the aid of his grad student Adam Carpenter and a Minnesota colleague, neuroscientist Giuseppe Pellizzer, Georgopoulos began training a monkey on a task that requires memorizing the order of events in time. The monkey watched a series of yellow spots pop up on a screen in a random order around an invisible circle. Then, after three or four of them were present on the screen, one spot would turn blue. The monkey's job was to move a cursor to the spot that had appeared right after the blue spot. It took a year and a half for the monkey to master the task, and when it did, the team spent an incredible 3 years training a second monkey to do it with up to five spots.

As the monkeys performed their task, the researchers recorded the responses of hundreds of neurons in the animals' motor cortices and found, as expected, that many of them showed a change in activity while the monkey was watching the spots, before any movement occurred. But they were surprised to discover that hardly any of these responses was specifically related to a spot's location. Instead, the researchers found that more than one-third of the recorded neurons showed an abrupt increase in firing only when a spot arrived in a certain place in the sequence—first, say, or second—no matter what its location. These neurons seemed to be specifically sensitive to "serial position."

"What is truly impressive is the magnitude and robustness of the effect," comments Patricia Goldman-Rakic, a Yale University neuroscientist. "Serial position is represented at least as prominently as movement direction." No single neuron could indicate a spot's serial position with certainty. But the more neurons monitored, the better their aggregate responses could specify this position, and the pattern of activity of 16 cells or more could pinpoint a spot's serial position with 100% accuracy, Georgopoulos says.

The data suggest that the motor cortex can play an active role in processing abstract information and is not simply a slave of cognitive regions that tell it what movements to direct. Georgopoulos emphasizes, however, that the region does not do this job alone, but in concert with the rest of the brain. Neurons in the motor cortex, he says, are "participants in a dynamically changing network" of cells in different brain regions that share whatever



SOURCE: GEORGOPOULOS ET AL.; ILLUSTRATION: P. MORRIGHAN

Monkey see, monkey remember. In this task, the monkey has to remember and point to the spot that appeared just after the one that turned blue.