The New York Times

September 2, 2013

Cognitive Science Meets Pre-Algebra

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TAMPA, Fla. — The math students at Liberty Middle School were not happy.

The seventh graders' homework was harder and more time-consuming at first, and many of the problems seemed stale. They were old, from weeks or months ago — *proportions, again*? — and solving them interrupted the flow of the students' current work.

"They were having to remember, and to work on, stuff they'd learned previously — plus the new material," their teacher, Jen DeMik, said of last semester's assignments. "They had to focus on several things instead of just one."

Or as 13-year-old Giulia Falabella, one of her students at the time, put it, "It took some getting used to, that's for sure."

But as little as Giulia and her classmates may have liked it, the curriculum was part of an unusual educational experiment — one of an increasing number using tools of cognitive psychology, which focuses on the mental dynamics behind thinking, remembering and problem solving.

The technique under study in Tampa, called interleaving, has become an especially hot area of interest among researchers. It mixes distinct but related problems or ideas — long division, say, and multiplying fractions — in daily homework assignments.

Most textbooks and schools do the opposite, concentrating or "blocking" lessons to drive home skills by having students practice one at a time, over and over. This is the equivalent of shooting 100 free throws in a row for basketball practice, or running through just the A minor scale for an hour's music lesson.

"The result is that you feel you've learned the material really well; people prefer blocked practice, when you ask them," said Robert A. Bjork, a psychologist at the University of California, Los Angeles. "But they do much better on later tests when they practiced interleaved, or mixed, sets of problems or skills. It's completely counterintuitive."

Dr. Bjork and others have shown that studying mixed sets of related things — paintings,

birds, baseball pitches — greatly improves people's ability to make quick, accurate distinctions among them, compared with studying as usual, in blocks. Others have found the same improvements when the items being mixed are specific kinds of problems, like calculating volumes, or exponents.

A growing number of cognitive scientists now believe that this cocktail-shaker approach could improve students' comprehension of a wide array of scientific concepts, whether chemical bonds, parallel evolution, the properties of elementary particles or pre-algebra.

The Tampa experiment is sponsored by the Institute of Education Sciences in the Department of Education, which uses randomized, controlled trials — similar to what the Food and Drug Administration demands in approving new drugs — to determine which educational methods work and which do not. It is the first rigorous, classroom-based test of interleaving in mathematics.

The researchers started small: eight seventh-grade pre-algebra classes, 140 students in all. "We didn't introduce anything new, or ask teachers to do any additional work," said the lead investigator, Doug Rohrer, a psychologist at the University of South Florida and a former math teacher himself; his co-authors were Robert F. Dedrick and Kaleena Burgess. "We simply rearranged the material they already use."

The material included four basic types of problems:

■ Linear equations: for example, solving for x if $3(x + 1) = x + 17$.

■ Word problems involving proportions. (Penelope's tractor requires 14 gallons of gas to plow 6 acres. How many gallons will she need to plow 21 acres?)

■ Graphs. (Graph $y = -3x + 1$.)

■ Slopes. (Find the slope of the line that passes through (9, 7) and (2, 4).)

The students were split into two groups. Half got interleaved assignments on the first two problem types — linear equations and word problems — and regular, blocked assignments on the second two types. The other half got the reverse: blocked homework for linear equations and word problems, and interleaved for graphs and slopes. The students scored near zero on these kinds of problems at the beginning of the study.

For the teachers involved in the study, the mixed assignments seemed, essentially, like review work. "Sometimes we do what we call 'bell work,' which is where we give them a little

review before each class," said Brendan Paul, another Liberty math teacher who helped run the study. "The difference here is that the review is built into the homework, every day."

Though the interleaved homework took longer at first, most of the students adjusted. "I usually need a lot of time to study for tests," said Marigny Duga, who was a student in Mr. Paul's class, "but doing this mixed homework, I felt like, when the test was coming I needed less time than usual, because everything was still pretty fresh in my head."

Over nine weeks, each student in the study got 10 assignments with 12 problems each. Same students, same problems. But each student got half a semester of mixed homework, and half a semester of blocked.

Two weeks after the last homework assignment, the researchers gave a surprise cumulative test.

The results were striking. Students scored 72 percent, on average, on the interleaved material. They scored 38 percent on the homework-as-usual problems. This is a large difference, but it's not unheard of in laboratory studies of interleaved practice, experts said.

Psychologists are not sure why mixed problem sets can improve learning. One possibility is that studying mixed platters of items makes a student ask, first, "What *kind* of problem am I looking at?" rather than blindly applying a single procedure to every problem in the assignment.

"Contrast this to a typical homework assignment, which might say 'The Quadratic Formula' right there at the top of the page," Dr. Rohrer said. "They know what strategy to use before they read the problem."

Another possible explanation is that interleaving reinforces the brain's associations between specific types of problems (say, calculating slope) and a matching solution strategy (dividing the vertical change by the horizontal change, or "rise over run"). The problem and the solving strategy become a linked pair.

Can these kinds of results hold up across school districts and over time?

It is far too early to know, experts said. "You have to think of the classrooms as single units, so it's a sample size of eight, which is small," said Daniel T. Willingham, a psychologist at the University of Virginia. "The effect of interleaving is exceptionally robust in the lab, in terms of aiding memory, and there is certainly nothing to object to in this particular study.

“But I’m much more concerned with how these lab-based techniques interact with everything else in the classroom: the different dynamics, different kids, different teaching styles. For example, some percentage of teachers are going to say, ‘This doesn’t fit with how I teach math.’ Period. A lot of other people are simply not going to grasp what’s required to make it work. The question is: Is it adaptable?”

Most psychologists who study learning think so. “Remember, learning is slower when you begin interleaving,” said John Dunlosky, a psychologist at Kent State University. “If you have both groups learn the material to the same level — that is, if you give the people doing interleaving a little extra time at the beginning — then the benefits of mixed practice will be even larger, I expect.”

Or, like scores of other educational reforms big and small, interleaving might get lost in an administrative thicket or garbled in translation, one more good idea overwhelmed by reality.

Dr. Rohrer wants to run a larger study, involving more than a dozen schools, some 80 classes and 1,600 students.

“A lot of ideas have fizzled out as they’re scaled up,” he said. “So we need a larger study to find out if the benefits hold up in more than a few classes. ”