Merging Cognitive Science and Curriculum to Strengthen Middle School Math

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Consider that colorful photographs, eye-catching illustrations, and captivating images intended to make textbooks more appealing may actually distract students from the lesson at hand. Or that asking students to simply solve math problems might not be as effective as having them explain the steps of solutions that are already worked out—even some that are worked out incorrectly.

Although such statements may sound counterintuitive, they reflect well-established research findings on the cognitive science behind student learning. And it is these and other such findings that are guiding researchers at WestEd's National Center on Cognition and Mathematics Instruction (the Math Center, funded by the U.S. Department of Education) as they apply research-based principles to revise a widely used middle school math curriculum. The redesign is intended to provide a kind of blueprint that curriculum developers can use to make their work—in any number of curricular areas—more effective.

"The center's work really is multifaceted," says WestEd's Steve Schneider, who directs the Math Center. "It's a curriculum engineering project where the modifications can be broadly applied. We hope what we generate can become a design template to guide others when revising their own instructional materials."

The center is translating research about how students process information into a set of design principles and applying those principles in the revision of existing curricula. Researchers are then testing "whether the same large learning gains found in labs will occur in authentic classroom settings that are using the revised curricula," says Jodi Davenport, Director of Research for the center.

Funded by a five-year grant from the U.S. Department of Education's Institute of Education Sciences, the Math Center is a collaboration between WestEd, the lead institution, and partners at Carnegie Mellon University, Temple University, the University of Illinois at Chicago, the University of Wisconsin–Madison, and Worcester Polytechnic Institute.

Research-based design principles

To revise an existing curriculum, the center's team applied four design principles that reflect cognitive science research findings:

1. Integrating visual images and verbal information in meaningful ways promotes understanding of key concepts and development of critical skills.

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2. Practice that is structured to give students opportunities both to solve problems and to study already worked-out problems (some of which may be solved incorrectly) promotes deeper conceptual understanding.
3. Spacing out the presentation and review of key concepts and facts over time helps students better retain what they learn.
4. Testing students periodically, accompanied by targeted feedback, gives students opportunities to practice retrieving knowledge and to learn from their mistakes.

According to Davenport, some of the principles—such as those related to spacing out learning and periodically testing—are derived from basic psychological concepts documented more than a hundred years ago; other principles have been recognized more recently. A core concept is that students have a "limited amount of working memory," she says, "and when many things are competing for that memory, it's important to keep the focus on what's relevant."

It is also significant that the Math Center researchers are applying the four design principles simultaneously, in combination, as they revise the math curriculum. This approach differs from other studies that have explored cognitive science principles typically by focusing on just one at a time.

For example, in the revised curriculum, a sixth grade unit on area and perimeter was reworked to take into account both of the first two design principles. In both the original and revised units, students were asked to sketch floor plans for a new bumper car ride that met certain specifications. In the original unit, the problem was accompanied by a photograph of an amusement park. In the revised version, the photograph was eliminated and replaced with a sketch of three possible floor plans for the new ride, including one that "does not meet the requirements." Students were asked to determine "Which one does it fail to meet?" and "How can you tell?"

Schneider explains that pictures like the one of an amusement park are not just filling space unnecessarily but actually distract students because such pictures are not directly related to the math of the problem. In this case, showing floor plans for the bumper car ride can better help students acquire the math content they need because the plans more closely represent the details of the problem.

"A change that simple, which strengthens the connection between the visual and verbal material, is sometimes all it takes to help students understand a concept," Schneider says.

Explaining problems that have been solved incorrectly, says Davenport, is increasingly being seen as "one of the most effective kinds of practice for students." Instead of just getting the answer to a problem, students must thoroughly understand the steps taken to arrive at a solution and must have the conceptual understanding to determine if and where an error was made. Ultimately this kind of practice "helps students not make that same mistake," says Davenport.

Testing the revisions in classrooms

A study involving 120 teachers at 87 schools in 17 states was conducted from January to June 2012. Its goal: to determine if sixth and eighth graders using the redesigned curriculum units showed greater improvements in math scores (as measured by pre- and post-tests) in comparison with peers using the original curriculum. To prepare, teachers took part in a two-day, online professional development workshop led by WestEd facilitators in which participants learned about the research behind the four design principles, studied the changes made to the curriculum, and practiced applying those changes to their lesson plans.

Each teacher involved in the study was randomly assigned to provide data from two specific middle school math units: one in its original format and the other as revised. Weekly logs completed by the teachers noted if and how they had applied elements of the four research-based principles to their instruction.

Data analysis is still underway, says Davenport, but "we are seeing trends going in the expected direction," in favor of the redesigned curriculum. Schneider reports that teachers describe the revisions as "very positive," noting that the changes "make sense and enhance the materials."

The Math Center is also conducting a study—which began in fall 2012 and runs through spring 2014—to evaluate the effectiveness of the entire revised seventh grade math curriculum. The first year of this study provided practice opportunities for teachers to gain familiarity with the design principles, and the second year focuses on testing the impacts of the revised curriculum in comparison with the original curriculum. This effort is intended to generate more findings about whether and for whom the revised materials improve outcomes.

Lessons learned

Schneider and Davenport say they hope the Math Center's work on the middle school math curriculum sheds light on the value to be gained when research findings from cognitive science are applied to curriculum development and teaching practices across the board. "The point," says Schneider, "is to use what the research tells us about how students process information—and to tailor instruction accordingly to support their learning."

According to Davenport, such strategic support is a matter of making conscious decisions when writing curriculum and developing instructional materials. "A lot of development that's happening now is arbitrary," she says. "It needs to be more targeted."

Specifically, she'd like to see curriculum writers and teachers everywhere focus on proven, practical measures, such as making sure instructional materials integrate visuals in strategic ways that complement a lesson's key concepts and skills, or finding ways to maximize the use of students' limited working memory.

"Little things, done over time, become cumulative, and can make a big difference," Davenport says. "So just spending a few extra minutes every day focusing on exactly the right information can lead, over the course of a school year, to much deeper understanding."

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