The Center
FOR COMPREHENSIVE SCHOOL
REFORM AND IMPROVEMENT

ISSUE BRIEF

www.centerforcsri.org

March | 2006

Love and MATH

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Some elementary teachers might have breathed a sigh of relief when it became clear that the new "highly qualified teacher" rules in No Child Left Behind (NCLB) would not require much in the way of subject-matter knowledge. Those rules asked middle and high school teachers to demonstrate proficiency in the subjects they teach, either by earning a college major or passing a test in those subjects, in addition to having a bachelor's degree and a teaching certificate.[1] However, although the law made a nod to elementary teachers knowing their subjects too, for K–5 teachers in most states, it required nothing new.

Of course, that didn't seem odd to most educators and administrators. After all, how much mathematics does a first- or second-grade teacher really need to know in order to teach arithmetic to 6- or 7-year-olds? While experts occasionally harrumph about teachers with weak math skills flocking to the lower grades, the issue certainly hasn't generated the outraged response that reports on "out-of-field teaching" in middle and high schools has during the last 10 years.

Indeed, a longstanding tenet of American education—one built into the very fabric of teacher training and licensure—is that elementary teachers need only *general* teaching skills and that having a caring personality is sometimes more important than how much math (or science or history) a teacher knows. In the lower grades, so the reasoning goes, even adults who have weak math skills themselves simply need to be sure they know enough to teach a given concept or skill. And they can do that by staying one step ahead of the children in the curriculum—for example, by brushing up on the rules for multiplying three-digit numbers the week before they begin a unit on it.

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Added Value of Specialized Knowledge

But an important new study published last year suggests that this conventional wisdom is very, very wrong. Researchers tested the mathematical knowledge of first- and third-grade teachers and then examined the impact of that knowledge on student gains in mathematics over the course of a year. The study revealed that a teacher's own mathematical knowledge has a substantial impact on student learning *even at the first-grade level,* a finding that left even the researchers themselves "modestly surprised."[2]

That impact remained even when researchers accounted for other factors that might influence student learning gains, including family background (the number of parents in the home, parent education levels, and family income), how often students were absent, teacher certification and experience, and how much time teachers spent on math lessons. And the impact was quite large: Children taught by educators who have high-level math knowledge gain the equivalent of about two or three weeks of extra instruction compared with students whose teachers have average math knowledge and skills. In fact, teacher knowledge had as big an impact on math learning as student poverty or race.

Because of the so-called "math wars" now raging in some states, it's important to note that the study wasn't conducted by fringe researchers with an ideological axe to grind or published in some obscure academic journal. The research team included Deborah Lowenberg Ball, dean of the School of Education at the University of Michigan, and the findings were published in the *American Education Research Journal,* the flagship publication of the nation's oldest and largest association of education researchers. Moreover, the study was part of a large-scale, longitudinal research project called the Study of Instructional Improvement, which has been tracking comprehensive reform and improvement in 120 U.S. schools for the past several years. (Visit www.sii.soe.umich.edu/ for more information.)

The researchers found that two kinds of teacher mathematical knowledge are important for student learning—"common" and "specialized." Common math knowledge includes basic mathematical concepts and procedures for solving basic problems, such as figuring out percentages or multiplying and dividing by fractions. In other words, common knowledge includes what anyone who was fortunate enough to benefit from good elementary and secondary math education would know.

But students benefited most when teachers *also* had an extra "fluency" in thinking about and dealing with basic mathematical concepts and problems—a "specialized knowledge" that goes beyond common math skills. Such teachers are good at puzzling out where a student went wrong in multiplying two three-digit numbers, for example, or knowing whether an unusual solution to a fractions problem would work for other kinds of problems the student might encounter later in the curriculum.

For example, three students might solve the problem 6x87 in three different ways, two getting the answer wrong and the other getting the answer right. Their teacher has to be able to analyze the work of the two who arrived at incorrect answers to understand—and help them understand—what they did incorrectly. If the third used an unusual approach to arrive at the correct answer, the teacher must signal whether that approach will always work with similar problems the

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student might encounter later rather than simply marking the problem correct or saying "good job."

Ball and her colleagues take pains to emphasize that this specialized math knowledge is still math knowledge rather than simply knowing how to teach well—in other words, *mathematical reasoning* rather than simply *instructional reasoning*. For example, "Appraising non-standard solution methods is not a common task for adults who do not teach. Yet, this task is entirely mathematical, not pedagogical: to make sound pedagogical decisions, teachers must be able to size up and evaluate the mathematics of these alternatives—often swiftly and on the spot."[3]

What's new about this particular study isn't the concern that some elementary teachers might lack important mathematical knowledge and skills, but the evidence that it matters so much even in the earliest grades. Indeed, a book by Liping Ma, a onetime student of Ball's now at the Carnegie Foundation for the Advancement of Teaching, kicked off an intense debate among math educators in 1999. Ma studied a group of elementary school teachers in China and another in the United States and documented that Chinese elementary school teachers had deeper knowledge of mathematics than their American counterparts.[4]

That book has been used to advocate for changes to preservice training, which, of course, might be part of the solution. However, Ma found that while Chinese teachers do enter teacher education with strong math skills, they developed "profound understanding of fundamental mathematics" *during their teaching careers.* Indeed, in China, adults who teach math to elementary school students *teach only math.*

Solving for X

The new research adds up to trouble for school staff, district administrators, and assistance providers who have gone about the business of school reform and improvement without questioning the longstanding assumption that teaching elementary math requires only basic math skills.

For example, efforts to improve math achievement often involve implementing new math programs. Leaders and assistance providers routinely consider the resources teachers will need to make a program work such as curriculum, textbooks, instructional materials, and time. They also consider how much professional development to provide to teachers. This research suggests they should pay special attention to whether teachers need professional development that addresses math skills.

There's no doubt the topic will be an uncomfortable one for many teachers. It's far easier to discuss how much training teachers will need to understand and use a new instructional technique, especially one that comes "bundled" in a new math program, than to talk about whether teachers have adequate mathematical knowledge and skills. Given teacher sensitivity to this issue, are there politic, nonthreatening ways to broaden the scope of the "needs assessment" stage of the school improvement process to allow for such questions?

Such efforts will be particularly important for closing achievement gaps. Ball and her colleagues found that low-income and minority students were more likely to have teachers with low-level math knowledge in elementary school—a fact they believe will make it hard for schools to help such students keep pace with their peers. Indeed, the researchers were surprised to find that the inequities were biggest for minority students: "We find these results shameful."[5]

Moreover, assistance providers, education leaders, and policymakers need to begin asking how they can help schools assess whether

teachers have sufficient math knowledge and identify those who do not. Guesswork alone will not do. Nor will teacher self-identification. Good school improvement efforts minimize uncertainty and base action on knowledge. Unfortunately, the assessments developed by the University of Michigan have not been converted into general use instruments that can be used to make judgments about individual teachers. (However, the researchers have released a fairly extensive set of sample items.[6])

Assistance providers, education leaders, and policymakers also will need to provide schools with strategies for dealing with knowledge deficits that are identified. Fortunately, another study conducted by two of the same researchers revealed that a teacher's math knowledge can be boosted by good professional development. "Our results show that teachers can learn math for elementary school teaching in the context of a single professional development program."[7] However, the training that benefited teachers most kept the math front-and-center, focusing on mathematical analysis and communication rather than general teaching strategies that might work for any subject.

Finally, assistance providers will need to help elementary schools directly confront deeply held, longstanding beliefs about what kinds of things younger students need in their teachers. That will not be easy. Many educators and even experts believe that focusing on the math skills of elementary grade teachers would be profoundly misguided. Indeed, in the striking conclusion to an article in last fall's *American Educator* magazine, Ball and her colleagues report that they have been heavily criticized for even conducting this kind of research in the first place. Critics have accused them of somehow cheapening the teaching profession:

> [The] negative responses we have received from some other education professionals are noteworthy. Testing teachers, studying teaching or teacher learning […], using standardized student achievement measures—each of these draws sharp criticism from some quarters. […] [Some critics] claim that we are "deskilling" or "deprofessionalizing" teachers by "testing" them.[8]

In response, the researchers argue that if empirical evidence shows something to be important for teaching and learning, researchers have an obligation to try to understand it, even if the findings run counterintuitive to our traditional beliefs about what makes a good teacher.

But let's go one step further. If that research shows that something can benefit student learning, we should expect school leaders and assistance providers to address it as they seek to improve schools. The challenge should not be to figure out how to improve math achievement *despite* low math knowledge and skills among teachers. The challenge should be to find ways to talk about and deal with that problem in ways that do not unduly antagonize or offend teachers.

After all, NCLB places a strong emphasis on mathematics for some very good reasons. Students who fall behind educationally seldom catch up later on, and this is especially true in math, a "cumulative" subject area that builds new knowledge upon foundational skills mastered previously. A weak math foundation can have profoundly negative consequences for young people later in life, including the following:

- Many American teenagers struggle with algebra when they reach high school, and researchers have found that failing ninth-grade algebra is a strong predictor of dropping out.[9]
- Multiple large-scale federal studies have revealed taking and passing high school math courses beyond algebra II has a strong impact on whether students complete college, regardless of family background.[10]
- Whether they graduate from college or not, young adults with low math skills now

> struggle to find decent jobs in an economy where skill demands have increased dramatically during the last 20 years—even in so-called "blue collar" jobs that require little or no postsecondary education.[11]

As Don Davis, the director of an apprenticeship program for union electricians in California told the *Los Angeles Times* in January, "If you want to work in the real world, if you want to wire buildings and plumb buildings, that's when it requires algebra."[12]

Therefore, even aside from the legal obligation to meet accountability standards for math in federal and state law, educators have a strong moral obligation to the adults children will someday become to ensure that students gain a strong foundation of math skills in the elementary grades.

In Sum. . .

Some might argue that the problem isn't elementary teachers' mathematical knowledge but their ability to teach math in new ways. That, of course, is also an important issue—one that is being addressed through everything from classroom materials and curricula to staff development and in-house math coaches. Many teachers are benefiting from such efforts. But the ability to use new curricula and techniques—from first grade forward—requires adequate knowledge of the subject matter itself. If anything, the current push to "teach for understanding" requires teachers to have a deeper understanding of the elementary math curriculum themselves.

Far from being radical, that sentiment reflects a growing consensus in the field. Last summer, the American Mathematical Society published a paper by a group of math educators and researchers trying to move beyond the current "math wars" by determining how much common ground they share and what the realm of consensus is. The paper concludes:

> Teaching mathematics effectively depends on a solid understanding of the material. Teachers must be able to do the mathematics they are teaching, but that is not sufficient knowledge for teaching. Effective teaching requires an understanding of the underlying meaning and justifications for the ideas and procedures to be taught and the ability to make connections among topics. Fluency, accuracy, and precision in the use of mathematical terms and symbolic notation are also crucial. […] Well-designed instructional materials, such as textbooks, teachers' manuals, and software, may provide significant mathematical support, but they cannot substitute for highly qualified, knowledgeable teachers.[13]

Finally, of course, no one would suggest that elementary school students also don't need caring classroom environments.[14] But the evidence is now clear. Children need math as well as nurturing.

Why can't we give them both?

This is the first in a series of issue briefs to be written for The Center for Comprehensive School Reform and Improvement during 2006. These commentaries are meant to help readers think beyond simple compliance with federal law or basic implementation of programs: What unacknowledged challenges must educators and leaders confront to help schools operate more effectively and to sustain improvement over the long run? In what ways does the conventional wisdom about teaching, learning, and school improvement run counter to current research and get in the way of making good decisions? What are the emerging next-generation issues that educators will face next year and five years from now? Readers can visit **www.centerforcsri.org** to obtain other papers in this series and to access additional information on school reform and improvement.

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Endnotes

[1] NCLB permitted states to establish additional, alternative ways for middle and high school teachers to demonstrate subject-matter knowledge—called the "high objective uniform state standard of evaluation (HOUSSE) provision" in policy circles—for example, through relevant experience and professional development. Most states have taken advantage of that flexibility.

[2] Hill, H. C., Rowan, B., & Ball, D. L. (2005, Summer). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal, 42*(2), 371–406. Retrieved March 6, 2006, from http://www-personal.umich.edu/~hhill/HillRowanBallAERJSummer05.pdf

[3] Hill, H. C., Rowan, B., & Ball, D. L. (2005, Summer). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal, 42*(2), 388. Retrieved March 6, 2006, from http://www-personal.umich.edu/~hhill/HillRowanBallAERJSummer05.pdf

[4] Ma, L. (1999). *Knowing and teaching elementary mathematics.* Mahwah, NJ: Erlbaum. Interested readers might want to consult a short review of Ma's book that does an excellent job summarizing her findings: Askey, R. (1999, Fall). Knowing and teaching elementary mathematics. *American Educator, 23*(4), 1–8. Retrieved March 6, 2006, from www.aft.org/pubs-reports/american_educator/fall99/amed1.pdf

[5] Ball, D. L., Hill, H. C., & Bass, H. (2005, Fall). Knowing mathematics for teaching. *American Educator, 29*(3), 44. Retrieved March 6, 2006, from http://www.aft.org/pubs-reports/american_educator/issues/fall2005/BallF05.pdf

[6] The sample items can be downloaded from http://sitemaker.umich.edu/lmt/files/LMT_sample_items.pdf

[7] Hill, H. C., & Ball, D. L. (2004, November). Learning mathematics for teaching: Results from California's Mathematics Professional Development Institutes. *Journal for Research in Mathematics Education, 35*(5), 330–351.

[8] Ball, D. L., Hill, H. C., & Bass, H. (2005, Fall). Knowing mathematics for teaching. *American Educator, 29*(3), 47.

[9] Balfanz, R. & Legters, N. E. (2004). Locating the dropout crisis. In Orfield, G. (Ed.), *Dropouts in America: Confronting the graduation rate crisis* (pp. 57–84). Cambridge, MA: Harvard Education Press. The authors note "Failing ninth-grade algebra is the reason many students are left back in ninth grade, which in turn is the greatest risk factor for dropping out" (p. 73).

[10] Adelman, C. (1999). *Answers in the tool box: Academic intensity, attendance patterns, and bachelor's degree attainment.* Washington DC: U.S. Department of Education, Office of Educational Research and Improvement.

[11] The American Diploma Project. (2004). *Ready or not: Creating a diploma that counts.* Washington DC: Achieve Inc. Retrieved March 6, 2006, from http://www.achieve.org/dstore.nsf/Lookup/ADPreport/$file/ADPreport.pdf

[12] Helfand, D. (2006, January 30). A formula for failure in L.A. schools. *Los Angeles Times.* Retrieved March 6, 2006, from http://www.latimes.com/news/education/la-me-dropout30jan30,0,3211437.story

[13] Ball, D. L., Ferrini-Mundy, J., Kilpatrick, J., Milgram, R. J., Schmid, W., & Schaar, R. (2005, October). Reaching for common ground in K–12 mathematics education. *Notices of the American Mathematical Society, 52*(9), 4. Retrieved March 6, 2006, from http://www.maa.org/common-ground/cg-report2005.pdf

[14] And some of those attributes are even necessary for teaching math. Ball and other researchers have found that one of the most important strategies numerate teachers use is "error analysis and correction," which involves helping students diagnose why they get the wrong answers to math problems. Teachers need to be able to establish a great deal of trust to correct the math errors of young children, either in a group setting or one-on-one, in ways that respect their feelings and do not turn them off to learning math.

Administered by Learning Point Associates in partnership with the Southwest Educational Development Laboratory (SEDL) and WestEd, under contract with the Office of Elementary and Secondary Education of the U.S. Department of Education.

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