Research suggests that timed tests cause math anxiety

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IN MY OPINION

Teachers in the United States are often forced to follow directives that make little sense to them and are far removed from research evidence. One of the initiatives mandated by many school districts that I place high in the category of uninformed policy is the use of timed tests to assess math facts and fluency. Teachers and administrators use these tests with the very best of intentions, but they use them without knowledge of the important evidence that is emerging from neuroscience. Evidence strongly suggests that timed tests cause the early onset of math anxiety for students across the achievement range. Given the extent of math anxiety, math failure, and innumeracy in the United States (Boaler 2009), such evidence is important for us all to consider. In this article, I summarize the evidence from neuroscience and describe an alternative pedagogical routine that teaches number sense and math fluency at the same time that it encourages mathematical understanding and excitement.

ALEXSTAR/THINKSTOCK

Math anxiety

Occurring in students from an early age, math anxiety and its effects are exacerbated over time, leading to low achievement, math avoidance, and negative experiences of math throughout life (Ramirez et al. 2013; Young, Wu, and Menon 2012). Educators have witnessed the impact of math anxiety for decades, but only in recent years have timed math tests been shown to be one cause of the early onset of math anxiety. Indeed, researchers now know that students experience stress on timed tests that they do not experience even when working on the same math questions in untimed conditions (Engle 2002).

In a recent study of 150 first and second graders, researchers measured students' levels of math anxiety, finding that children as young as first grade experienced it and that levels of math anxiety did not correlate with grade level, reading level, or parental income (Ramirez et al. 2013). Other researchers analyzed brain-imaging data from forty-six seven- to nine-year-old children while they worked on addition and subtraction problems and found that those students who "felt panicky" about math had increased activity in brain regions associated with fear. When those areas were active, decreased activity took place in the brain regions that are involved in problem solving (Young, Wu, and Menon 2012).

Beilock and her colleagues conducted brain scans to study the ways in which anxiety affects individuals, showing that children compute with math facts—such as those required in timed tests—by recalling information that is held in the working memory (Beilock 2011). The more working memory an individual holds, the greater potential he or she has for academic success (Engle 2002). Beilock and her colleagues found that when people are stressed, the pressure blocks their working memory and facts with which people are familiar *cannot be recalled*. Readers may recognize this process from any stressful or public situation when they have had to work with familiar math but found that their "mind has gone blank." This is the impact of stress blocking the working memory. Importantly, Beilock and her colleagues found that math anxiety influences those with high rather than low amounts of working memory—precisely those students who have the greatest potential to take mathematics to high levels. When students who experience stress in timed conditions find that they cannot access their working memory, they underachieve, which causes them to question their math ability and, in many cases, develop further stress and anxiety.

Timed tests in the United States

Many school districts across the United States use timed tests as a regular part of instruction. Starting in first grade in my local school district, students receive a fifty-question test to complete in three minutes. The district requires the tests to be given once per term, but some teachers give them weekly. One teacher explained that she does so because the first time she gave the test, many of her students cried; she now wants to get her students "used to them."

I asked teachers of the second- and fourth-grade students in one school to have students write about how the tests made them feel. The students' reflections showed that the test prompted anxiety in at least one-quarter of each class and that anxiety did not correlate with test success. Indeed, some students who completed all fifty questions correctly were those who indicated the most severe anxiety, talking about being "scared" when they were asked to take the test (see responses from fourth and second graders in the **sidebar** below). Some students cope with the pressure created by timed tests, but for a significant number of high and low achievers, timed tests create fear, stress, and anxiety.

In addition to the powerful negative emotions that timed tests cause, they give students a strong message about math—that it is a performance subject, the main purpose of which is to order and categorize students, rather than a rich and diverse subject that students should enjoy (Boaler 2009). In too many math classrooms, students believe that their role is to *perform*—to show they know math and can answer questions correctly—rather than to learn. I was reminded of this recently when a colleague of mine reported that her first-grade son came home and complained about his math class. When she asked what was wrong, he replied, "It's too much answer time and not enough learning time" (Lambert 2013). In a separate publication outlining the importance of students developing a "growth mindset" (Boaler 2013), I describe ways in which open tasks encourage the opportunity for important learning and for viewing math as a *learning subject*, whereas narrow and closed tasks encourage students to develop harmful, fixed mindsets.

The impact of taking a timed test is sufficiently powerful that students also frequently come to believe that memorizing math facts is the most important part of mathematics—really the essence

"It's too much answer time and not enough learning time."

Fourth and second graders' views of timed tests

Fourth graders responded in the following manner to the request to complete this sentence: "This test made me feel . . . "

- "Worried that I won't finish."
- "Nervous. I know my facts well, but it just scares me that I might get a bad score."
- "I feel nervous because I don't like tests that much."
- "Nervous because I am afraid I will not finish, or [I will] make a mistake."
- "I feel nervous. I know my facts, but it just scares me."
- "I feel pressured."

Second graders responded with these phrases:

- "Not grat [great]"
- "Upset"
- "Nrvis [nervous]"
- "Mad"
- "Nevis [nervous]"
- "That I'm terribul [terrible] at math"
- "Unhappy"

of math. Students also suffer from one of the most damaging myths that pervades U.S. math classrooms: the belief that *good* math performance is *fast* math performance. Award-winning mathematician Laurent Schwartz reflected in his 2001 autobiography that he often felt he was "unintelligent" when he was in school because he was one of the slower students:

> At the end of the eleventh grade, I took the measure of the situation, and came to the conclusion that rapidity doesn't have a precise relation to intelligence. What is important is to deeply understand things and their relations to each other. This is where intelligence lies. The fact of being quick or slow isn't really relevant.

Unfortunately, many students across the United States come to believe that fast students are those who have the most potential, meaning that many slower but deep thinkers turn away from math. The hallmark of high-level mathematical thinking, as Schwartz reflects, is working in depth, not working at speed. Timed tests as well as other speed-related materials (such as flash cards) cause slow, strong mathematical thinkers to become discouraged in class, develop math anxiety, and turn away from the subject.

Encouraging number sense and automaticity

Some districts use timed tests because of words such as *automaticity* in the new Common Core State Standards for Mathematics (CCSSM) (CCSSI 2010). But much better methods of teaching automaticity exist that also help students develop the conceptual understanding of mathematics that they urgently need (Boaler 2009). *Number sense*—the ability to work flexibly with numbers, decomposing and regrouping them with confidence—is so critical to young children that it is known to separate high achievers from low achievers in mathematics (Gray and Tall 1994, Boaler 2009). Pedagogical strategies called *number talks* (Parker 1993, Richardson 2011), also sometimes called *math talks*, help students develop math fluency and number sense at the same time. Importantly, they do so while showing students the flexibility and creativity within mathematics.

In a typical number talk, teachers give all students a number problem, such as 25 + 35, 23 – 15, or 18 × 5. Problems can involve any number operations—addition, subtraction, multiplication, or division—and they can be posed at any level of difficulty. The problems chosen should be those that generate many different solution paths. After the teacher poses the problem, he or she asks students to think of ways to solve it in their heads and to show their thumb, privately, when they have a solution. The reason for "quiet thumbs" rather than raised hands is to keep students from feeling intimidated or rushed when they see other students waving hands to show they have solved the problem. When the teacher sees the majority of thumbs up, she asks students to share their answers. If more than one student answers, teachers typically record the different answers without passing judgment on the "correctness" of the answers. Teachers then ask students to show how they have arrived at their answer. When I have taught middle school using number talks, students typically share six to eight different ways of arriving at the correct answer (see Boaler 2009). As students share their thinking, teachers record all their different methods next to one another on the board and ask students—by using such prompts as the following—to reflect on the different methods:

- Which ones are similar?
- Could we use the same method with different numbers?
- Would this method always work?

The visual representation of solutions is also helpful for students. In a recent online course I taught for teachers, I showed different visual representations of solutions for the expression 12 × 15 (see **figs. 1–7**). For the methods depicted in **figures 4**, **6**, and **7**, I asked students for visual representations of the solutions.

Different variants of number talks exist; some teachers ask students to indicate with their fingers if they have more than one method, for example. Number talks do not take long; they are short pedagogical routines (Kazemi, Lampert, and Ghousseini 2007) that take about ten minutes of lessons, but they achieve an incredible amount in that time. When I have used them with struggling seventh and eighth graders, students have reported that the number talks at the start of lessons completely changed their views of math. Many of them were incredulous to see an abstract number problem solved in eight different ways. They learned the critically important practice of number flexibility (Gray and Tall 1994), and they became more fluent with math facts. Number talks also work well with students of different achievement levels because students who know number facts well are usually fascinated to see and understand different methods, and students who are at an earlier stage of understanding also learn a great deal from the numerical solution paths. I have used the same problems with struggling seventh graders, Stanford freshmen, and CEOs of successful businesses with equally high engagement. Parrish (2010), Harris (2001), and Boaler (2009) give different examples of number talks.

One teacher explained that she [gives weekly timed tests] because the first time she gave the test, many of her students cried; she now wants to get her students "used to them."

CCSSM (CCSSI 2010) asks that students develop *automaticity* and that they know math facts by heart. Students can practice math facts in many ways, without the pressure of speed, including the use of hundred charts and many of the games and apps that have emerged in recent years. Number talks play an important part in the development of fluency: Students who answer mental number problems on a daily basis quickly commit the math facts they use to heart, at the same time developing something much more important—number sense.

One reason that teachers give timed tests is to encourage students to work quickly with math, to help them achieve highly on math tests. But giving students

Seven representative solutions for the expression 12 × 15

FIGURE 1

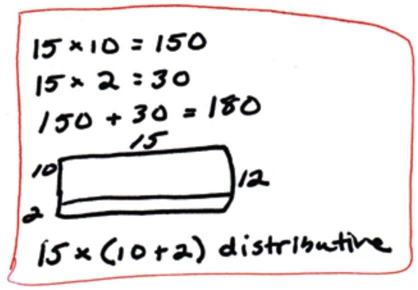

FIGURE 2

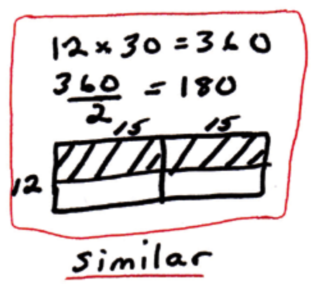

FIGURE 3

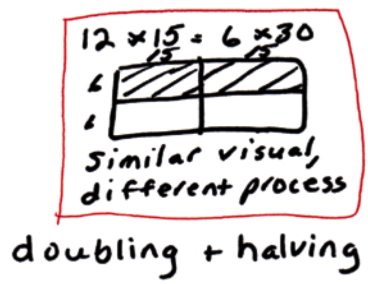

FIGURE 4

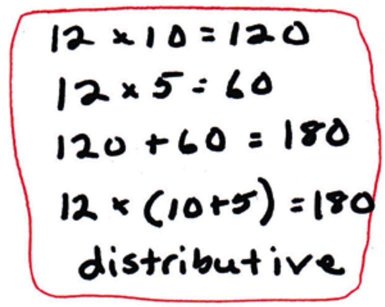

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FIGURE 5

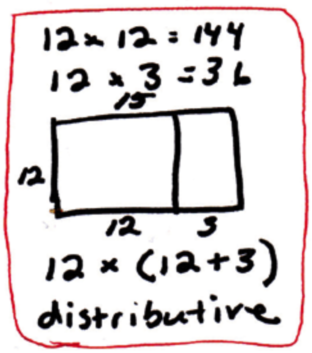


FIGURE 6

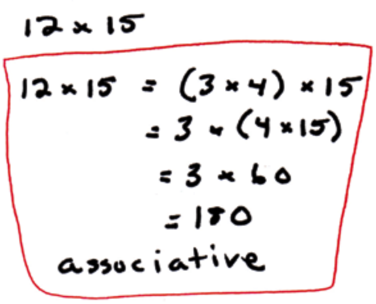
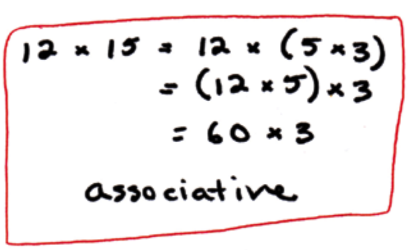


FIGURE 7



timed tests often achieves the opposite of this goal—creating math anxiety and a fear of mathematics that hinders future test performance. When taking timed tests, children who are fast usually remain fast while children who are slow remain slow—and become slower as math anxiety sets in. Teaching students to develop fluency and work at a reasonable pace is something that is achieved through the careful development of numerical understanding in the early years of school. Learning is a process that takes time, and it cannot be accelerated by methods that encourage speed at the expense of understanding.

The best mathematical learning environments are those in which students are encouraged to appreciate the beauty and diversity of math, learning new ideas without pressure or anxiety. Many students turn away from math in their early years because they feel that their creativity and open thinking close down as they are forced to follow standard rules and procedures. Mathematics is a multidimensional subject that should be introduced in the early years through a flexible, visual, and creative approach that values students’ thinking at all times (Boaler 2009). Number talks achieve these goals while teaching students numerical flexibility and automaticity. All educators want students to succeed in math and develop a love of math, but policies that require testing young children under timed conditions may be inadvertently achieving the opposite.

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COACHES' CORNER

A critical Common Core tool: Progressions documents

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The Progressions documents, funded by the Brookhill Foundation, preceded the Common Core State Standards in Mathematics (CCSSM) (CCSSI 2010) and provided its foundation. The Progressions describe the conceptual development of a topic strand across several grade levels. Once completed, each strand was sliced into grade-level standards, on the basis of the logical structure and sequence of mathematics and children's cognitive development.

The Progressions documents explain why standards are sequenced the way they are, call attention to areas in which misunderstandings are common, and offer suggestions and pedagogical solutions. They provide a critical tool (a) as a mechanism between mathematics education research and the standards, (b) to assist in long-range, unit, weekly, and daily planning, and (c) for math leaders and coaches to share with classroom teachers. Each Progressions document contains the following:

- An overview
- A detailed discussion of the work in each grade level
- Connections to the Standards for Mathematical Practice
- Concrete examples that may be used for instruction

The Progressions documents should be considered by every district, school, and teacher as one of the most useful tools for professional development and curriculum design. The documents can be found at http://ime.math.arizona.edu/progressions/. On the home page, simply click on a link that describes the progression of any content strand and grade-level band, such as the Draft K–6 Progression on Geometry, the Draft K–5 Progression on Number and Operations in Base Ten, or the Draft Grades 3–5 Progression on Number and Operations–Fractions. You can also find additional information about the Progressions project and its brilliant working team.

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