Speed and Time Pressure Blocks Working Memory

by Jo Boaler
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For about one-third of students, the onset of timed testing is the beginning of math anxiety (Boaler, 2014a, 2015). Sian Beilock and her colleagues studied people's brains through MRI imaging and found that math facts are held in the working memory section of the brain (Beilock, 2011). But when students are stressed, such as when they are taking math questions under time pressure, the working memory becomes blocked, and students cannot access math facts they know (Beilock, 2011 Ramirez, et al, 2013). As students realize they cannot perform well on timed tests, they start to develop anxiety and their mathematical confidence wears away. The blocking of the working memory and associated anxiety is particularly common among higher-achieving students and girls (Ramirez et al, 2013; Boaler, 2015). Conservative estimates suggest that at least a third of students experience extreme stress related to timed tests, and these are not students from any particular achievement group or economic background. When we put students through this anxiety-provoking experience, they distance themselves from mathematics.

Math anxiety has now been recorded in students as young as five, and timed tests are a major cause of this debilitating, often lifelong condition (Ramirez, et al, 2013).
In my classes at Stanford University, I encounter many undergraduates who have been traumatized by their math experiences, even though they are among the highest-achieving students in the country. When I ask them what led to their math aversion, many talk about timed tests in second or third grade as the major turning point when they decided that math was not for them. Some of the students, especially women, talk about the need to understand deeply, a very worthwhile goal, (see Boaler, 2014b) and being made to feel that deep understanding was not valued or offered when timed tests became a part of math class. Students may have been doing other, more valuable work in their mathematics classes, focusing on sense making and understanding, but timed tests evoke such strong emotions that

students often come to believe that being fast with math facts is the essence of mathematics. This is extremely unfortunate. We see the outcome of the misguided school emphasis on memorization and testing in the numbers of students dropping out of mathematics and the low numbers of women and people of color in math-based college majors. As long as we keep putting students under pressure to recall facts at speed we will not erase the widespread anxiety and dislike of mathematics that pervades the United States (Silva & White, 2013).

So how do students learn math facts?

Youcubed's paper "Fluency without Fear", includes the evidence on math facts and the brain and a range of activities that teachers and parents can use to teach number sense and enable important brain connections.

The best way to learn math facts is to offer conceptual mathematical activities that help students learn and understand number relationships. Brain researchers studied students learning math facts in two ways. One approach was through strategies; for example, working out 17 × 8 by thinking about 17 × 10 (170) and subtracting 17 × 2 (34); the other strategy was memorization of the facts (17 × 8 = 136). They found that those who learn through strategies achieved "superior performance" over those who memorized. Strategy Users solved test questions at the same speed as memorizers and showed a better ability to transfer their knowledge to new problems. The brain researchers concluded that automaticity should be reached through understanding of number relationships, achieved through thinking about number strategies (Delazer et al., 2005).

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In another important study, researchers found that the most powerful learning occurs when we use different areas of the brain (Park & Brannon, 2013). Some parts of the brain handle symbolic information; others handle visual and spatial information. Researchers found that mathematics learning and performance are optimized when different areas of the brain are communicating (Park & Brannon, 2013). Researchers also found that when students were working on math fact questions, the most successful students were those who exhibited the strongest connections between different areas of the brain. The implications of this finding are extremely important for mathematics learning, as they tell us that learning the formal abstract mathematics that makes up a lot of the school curriculum is enhanced when students are using visual and intuitive mathematical thinking. See visual post for more on ways to encourage visual math.

What is Mathematics?

A serious problem we face in math education is that people believe that mathematics is all about calculating and that the best mathematics thinkers are those who calculate the fastest. Some people believe something even worse— you have to be *fast* at math to be *good* at math. Yet mathematicians, whom we could think of as the most capable math people, are often slow with math. I work with many mathematicians, and they are simply not fast math thinkers. I don't say this to be disrespectful to mathematicians; they are slow because they think carefully and deeply about mathematics. Laurent Schwartz won the Fields Medal in mathematics and was one of the greatest mathematicians of his time. When he was in school, he was one of the slowest math thinkers in his class. In his autobiography, *A Mathematician Grappling with His Century* (2001), Schwartz reflects on his school days and how he felt "stupid" because his school valued fast thinking, but he thought slowly and deeply:

I was always deeply uncertain about my own intellectual capacity; I thought I was unintelligent. And it is true that I was, and still am, rather slow. I need time to seize things because I always need to understand them fully. Towards the end of the eleventh grade, I secretly thought of myself as stupid. I worried about this for a long time.

I'm still just as slow . . . . 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. (Schwartz, 2001)
Keith Devlin is a Stanford mathematician, and NPR's Math Guy. Keith also talks about being slow with math, and the misconceptions that arise when we focus on competition math, such as Olympiads because:

"Competition mathematics is in many respects a very different activity than the professional mathematics that most of us in the business pursue. For one thing, competition math requires speed, whereas many good mathematicians are slow thinkers. (I certainly am.)" Devlin in http://devlinsangle.blogspot.com/

Maryam Mirzakani is a mathematician at Stanford who recently won the Fields Medal, the world's top prize in mathematics. Maryam is an amazing woman who studies hyperbolic surfaces and who recently produced what has been called "the theory of the decade." In news articles on her work she is shown sketching ideas on large pieces of paper on her kitchen table, as her work is almost entirely visual.

When we look at mathematics in the world and the mathematics used by mathematicians, we see a creative, visual, connected, and living subject. Yet school students often see mathematics as a dead subject—hundreds of methods and procedures to memorize that they will never use, hundreds of answers to questions that they have never asked. When people are asked about how mathematics is used in the world, they usually think of numbers and calculations—of working out mortgages or sale prices—but mathematical thinking is so much more. Mathematics is at the center of thinking about how to spend the day, how many events and jobs can fit into the day, what size of space can be used to fit equipment or turn a car around, how likely events are to happen, knowing how tweets are amplified and how many people they reach. The world respects people who can calculate quickly, but the fact is, some people can be very fast with numbers and not be able to do great things with them, and others, who are very slow and make many mistakes, go on to do something amazing with mathematics. The powerful thinkers in today's world are not those who can calculate fast, as used to be true; fast calculations are now fully automated, routine, and uninspiring. (see Boaler, 2013) The powerful thinkers are those who make connections, think logically, and apply the breadth and depth of mathematics to a variety of problems.

This article contains excerpts from Jo Boaler's new book, Mathematical Mindsets: Unleashing Students' Potential Through Creative Math, Inspiring Messages and Innovative Teaching

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