HOW TO

ACCELERATE LEARNING WITH NEUROSCIENCE

The science of how we learn provides guidance for effectively accelerating math achievement.

MIND EDUCATION

Contents

The Challenge

The COVID-19 pandemic exacerbated existing gaps in U.S. students' math achievement. According to the 2022 School Pulse Panel, 64% of public schools reported that the pandemic played a major role in students being behind grade level at the start of the 2021-22 school year. Despite the Herculean efforts of teachers and administrators, supported by billions of dollars of federal funding, 45% of public schools said that at least a quarter of their students finished the 2021-22 school year behind, too.

An NWEA report found that student math achievement at the end of the 2021–22 was down by 5 to 10 percentile points. And specific groups of students continue to be disproportionately impacted: Black, Hispanic, and American Indian/Alaska Native (AIAN) students, as well as those who live in poverty.

While NWEA found younger students made some progress toward closing achievement gaps in math in the 2021-22 school year, for 7th and 8th graders, the achievement gap held steady or widened. If they continue learning recovery at the same pace, current 4th, 5th and 6th graders will need 3-5 years to close the achievement gap. Current 8th and 9th graders will need more than 5 years – the rest of their K-12 career.

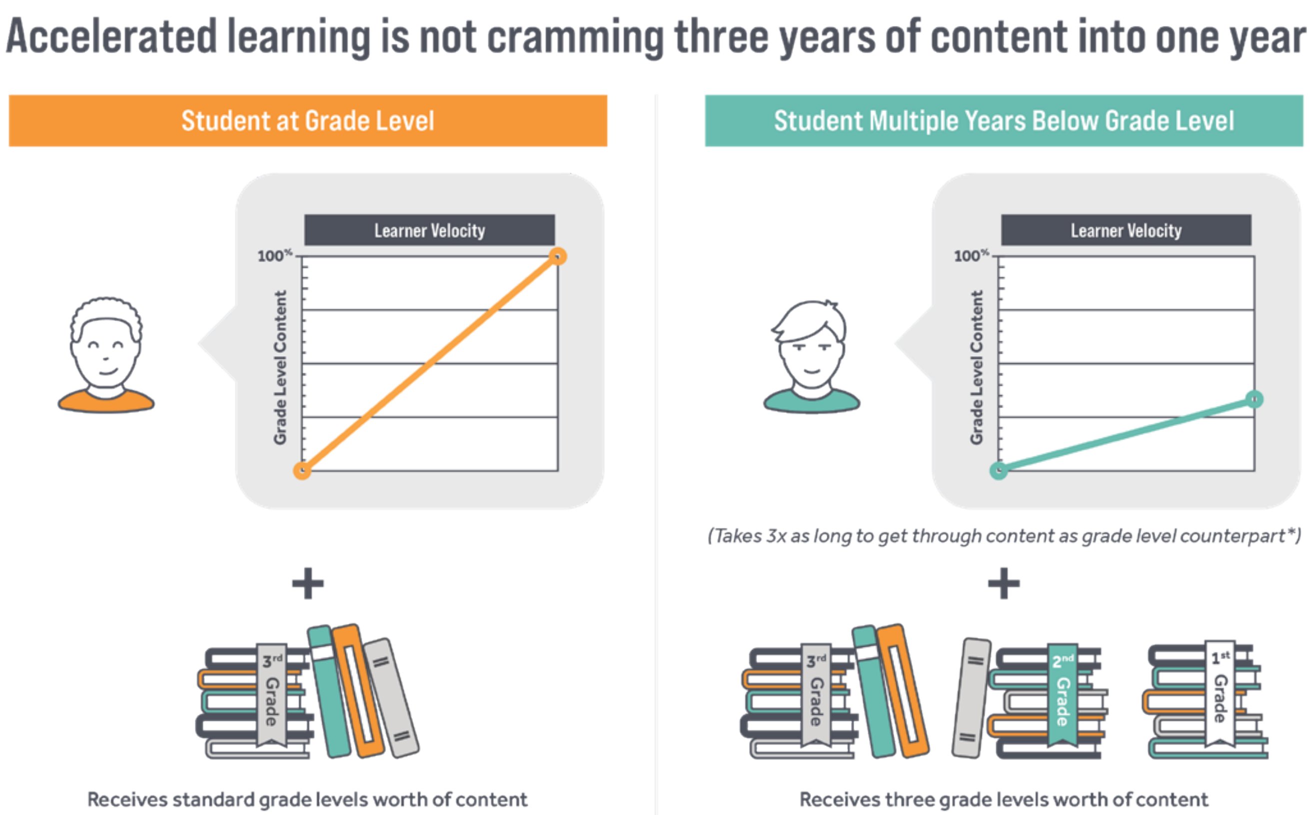
The imperative is clear: schools must accelerate math learning to restore – and hopefully, exceed – pre-pandemic achievement levels.

But the question remains, how?

The myth of "catching up"

Trying to cram two or three years of content in one school year is a self-defeating endeavor for both the student and the teacher. It's simply not logical to think that a student who is below grade level is going to cover two or three times the content as their on-grade-level peers – especially using traditional approaches. Students are not magically going to "catch up." They're going to stay behind.

At an even more fundamental level, students deserve to be presented with grade-level content as a matter of equity. Saddling students with low expectations, and spending too much time on below-grade-level content can have long-term negative effects, as detailed in TNTP's report, the Opportunity Myth.



> **"When students who started the year behind had greater access to grade-appropriate assignments, they closed the outcomes gap with their peers by more than seven months."**
>
> —The Opportunity Myth, TNTP

For nearly 30 years, MIND Research Institute has brought together neuroscientists, mathematicians and educators to apply the neuroscience of learning to math education. Here, we take a closer look at the neuroscience behind learning, and strategies you can use to truly accelerate learning for your students.

Common mistakes that do not accelerate learning

Through the School Pulse Panel, 39% of all public schools reported that they used accelerated instruction in the 2021-22 school year, but less than one-third said accelerated instruction was "very" or "extremely effective."

So, what actually accelerates learning? It helps to first consider what does not accelerate learning:

- Going through the curriculum faster
- Trying to cram two or three years of curriculum into one year
- Filling gaps or holes in understanding
- Focusing on skills gaps
- Checking boxes
- Shallow learning
- Teaching the same thing, the same way, again... and hoping for a different result

As educators, we tend to focus on teaching – how best to deliver information and knowledge to our students. So it's logical that we would try to accelerate learning by focusing on how we teach.

Many approaches to accelerate learning focus on re-teaching information to fill gaps in student understanding from previous years, while hoping against hope to catch up to the current year's learning objectives as well.

Before asking the question, "How do we teach?" we need to ask, "How do students learn?"

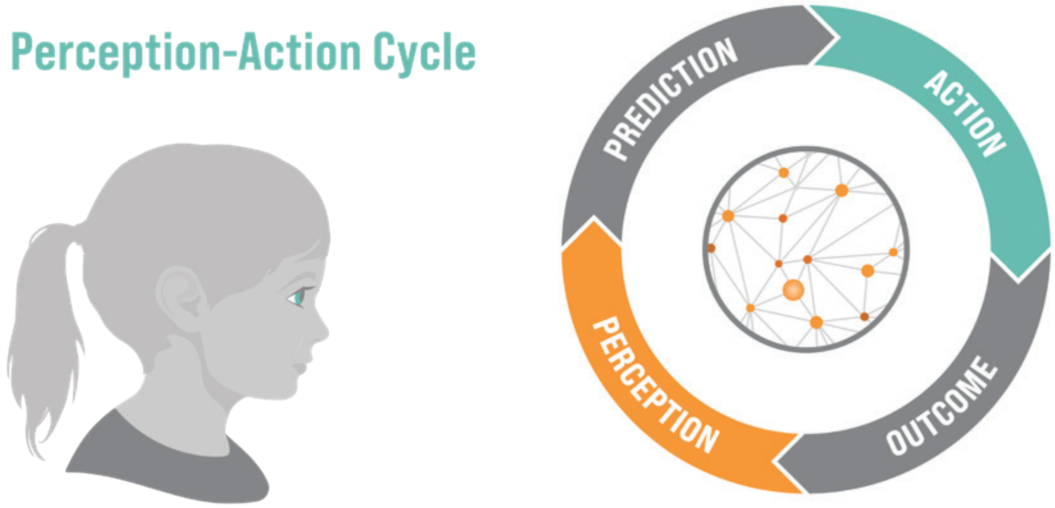
Neuroscience of Learning

To accelerate learning, we need to plug into neuroscience to supercharge the brain's natural learning process.

Perception-action cycle

We learn through a constant flow of information between the world around us and our brains. Neuroscientists call this the perception-action cycle.

The perception-action cycle is a universal learning mechanism for humans – and, in fact, for all mammals. Understanding how our brains learn, and leveraging this powerful natural process, is one of the secrets to accelerating learning.



Watch the video: What is the Perception-Action Cycle

Whenever we're tasked with solving a problem, we use our existing schema to make a prediction, "Here's what I think will happen." Then, we take action, and the consequences of our choices are revealed. We perceive the outcome, literally by seeing it, and inside the brain – in the hippocampus – the prediction we made is compared to our perception.

If we are correct, and our prediction and perception match, then the hippocampus floods chemicals along the neural networks to reinforce that schema, making it stronger. This is how we build schemas and conceptual understanding.

Of course, we learn from our mistakes, too. Failure is a natural – and even essential – part of the learning process. Sometimes, the schema that fired up is the wrong one, causing us to make a different prediction and take a different action.

As we perceive an outcome which does not match our prediction, the hippocampus sends a signal that deprioritizes that schema in the brain. So, the next time we see a problem like this, this schema is much less likely to influence our thinking. This is how misconceptions are rectified.

When we make a mistake, a second signal is also emitted from the hippocampus. This one sparks curiosity. As you experience that "huh, that's weird," moment, your brain gets the message that it's time for you to learn something new. You're ready to build a new schema.

> **"Math is not a spectator sport. It's not a body of knowledge, it's not symbols on a page. It's something you play with, something you do."**
>
> — Keith Devlin,
> emeritus mathematician,
> Stanford University

Accelerate Feedback

Feedback is essential to the learning process. A feedback-rich learning environment invites and encourages students to repeat the perception-action cycle, again and again, strengthening schemas, correcting misapprehensions and developing new schemas, as needed. Accelerating learning requires giving students more opportunity to repeat the perception-action cycle in a safe, feedback-rich environment.

Critically, the kind of feedback that fuels the perception-action cycle actually shows the student how their prediction was right or not, and provides guidance for the student to course-correct their understanding.

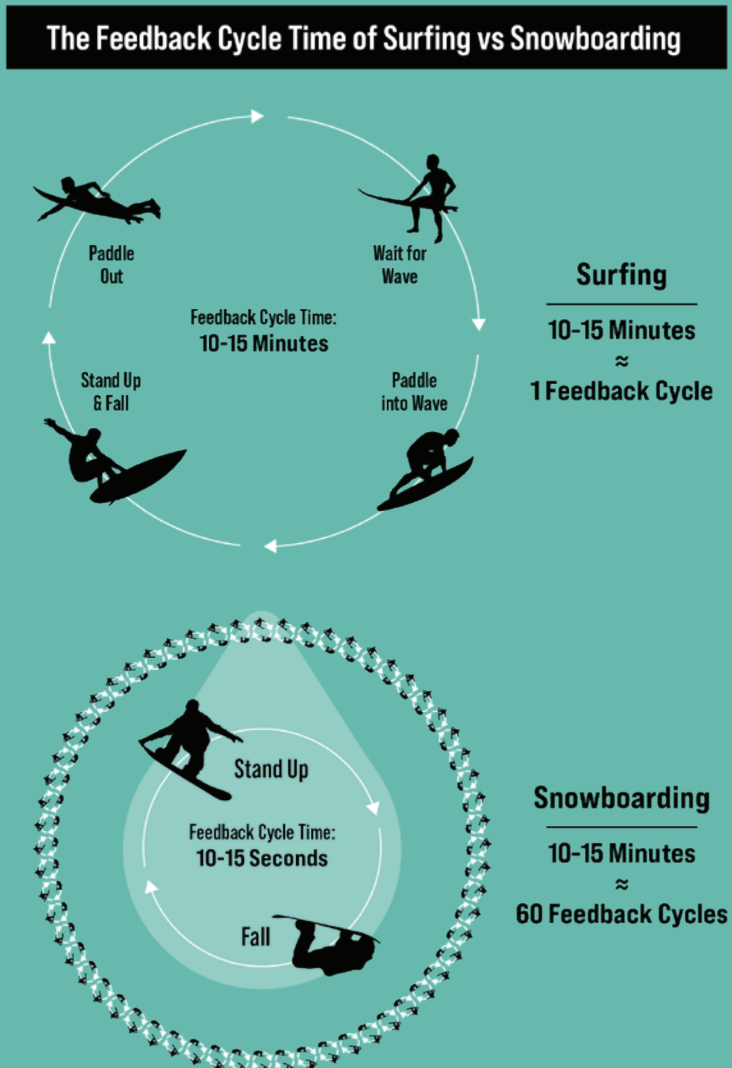
What can you learn faster: surfing or snowboarding?

Surfing and snowboarding both involve cutting across the surface of water – liquid or frozen – on a sturdy board that's often coated in fiberglass. Learning to skillfully do either involves a lot of falling down and getting back up.

But it takes much, much longer to learn to surf well than to snowboard, and the reason goes back to the perception-action cycle.

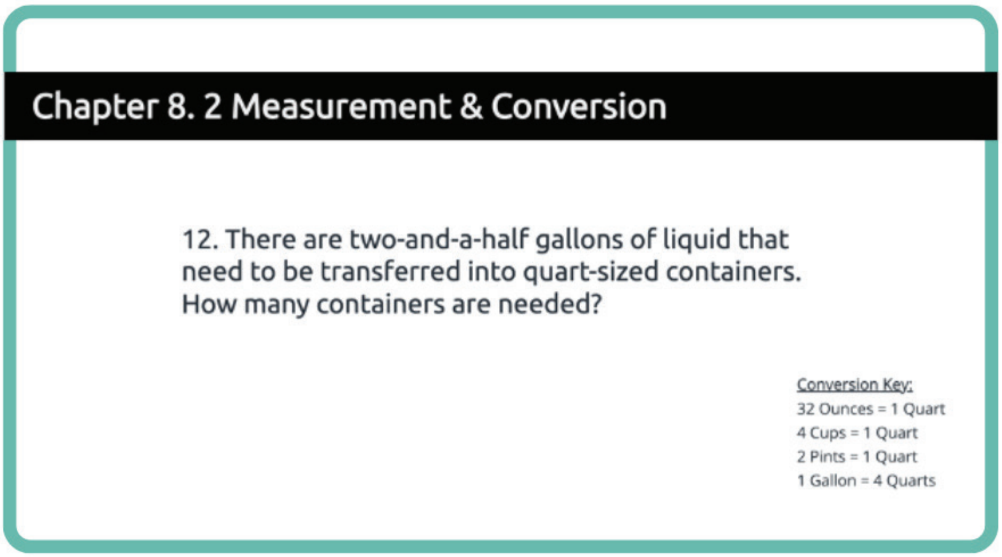
When you fall off of your surfboard, you have to get back on, paddle back out to where the waves are breaking, and wait patiently for another wave to come your way. At best, several minutes will pass before you have another chance to ride a wave.

Snowboarding can be learned much more quickly. When you fall, you can get right back up and within seconds be cruising down the hill again. You can fall over and over, building and strengthening your schemas for snowboarding through the perception action cycle. Meanwhile, someone in the ocean would still be laying on their surfboard, waiting for another wave and another opportunity to learn.



To leverage students' natural perception-action cycle in the classroom, you need to create an environment rich with formative feedback. There are many vehicles for providing feedback in a classroom environment: collaborative learning where feedback is provided by peers, problem-driven learning where feedback is slow-dripped through the problem solving process, and even direct instruction where a teacher provides explanations on solving a practice problem all provide opportunities for formative feedback. The key is engaging students in a process of making predictions and receiving feedback from those predictions.

An instructor's careful and intentional focus on creating a feedback-rich environment is essential in the math classroom. In a typical textbook math problem like the one below, there is no inherent feedback. A teacher must actively cultivate an environment that provides feedback as students work through the problem.



Chapter 8. 2 Measurement & Conversion

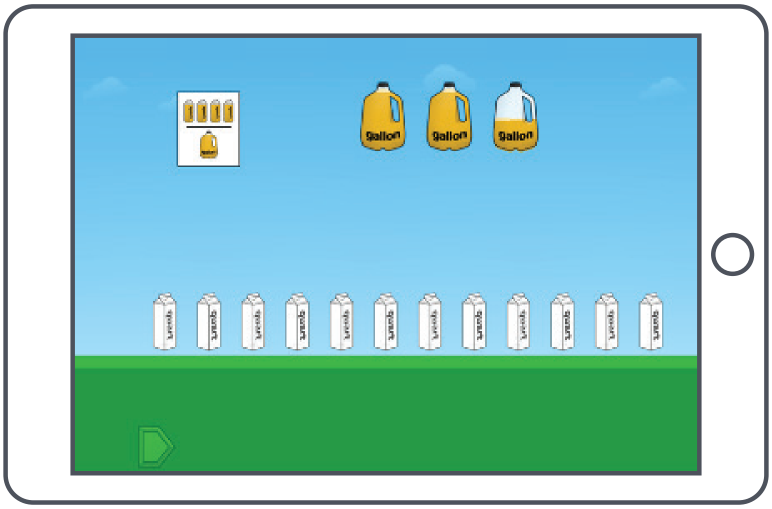
12. There are two-and-a-half gallons of liquid that need to be transferred into quart-sized containers. How many containers are needed?

Conversion Key:
32 Ounces = 1 Quart
4 Cups = 1 Quart
2 Pints = 1 Quart
1 Gallon = 4 Quarts

However, the instructor does not have to be the sole vehicle to facilitate feedback feedback vehicle in the math classroom.For example, in a digital medium, formative feedback can actually be *built into* the problem itself, providing a personalized response for the student that fuels the perception-action cycle *in every single math problem.*

Example: Formative feedback

In this interactive activity, students are presented with a similar conversion problem:



Try it: Play with the [**Volume Conversion Tool**]

The student selects how many quarts they think will be filled by the 2 ½ gallons. Then, their answer animates to show why it is right or wrong, providing immediate formative feedback. As a result, this process leverages the perception-action cycle, firing up the hippocampus to strengthen schemas, correct misunderstandings, and build new schemas.

A vehicle such as this creates a learning environment that gives students lots of opportunities to make mistakes, get corrective feedback, and try again within an extremely short cycle time — thus, accelerating their learning.

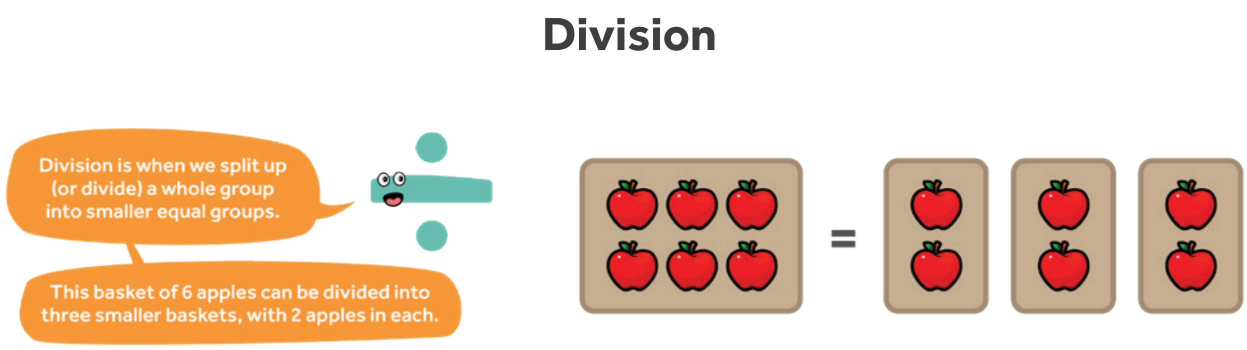
> **"ST Math has met our needs better than anything else out there. The combination of highly engaging and, for lack of a better word, fun content and research-based conceptual math instruction, I believe is a major reason we didn't experience as much 'learning loss' as we originally anticipated we would."**
>
> — Scott Borba, superintendent, Le Grand Union Elementary School District, California

Accelerate Students to Grade Level

To prevent students who are behind grade level from spending lots of time on previous years' content, their grade-level content must be made highly accessible. Onramps to new lessons need to be easily grasped by students across a wide range of skill and knowledge levels, then carefully scaffolded.

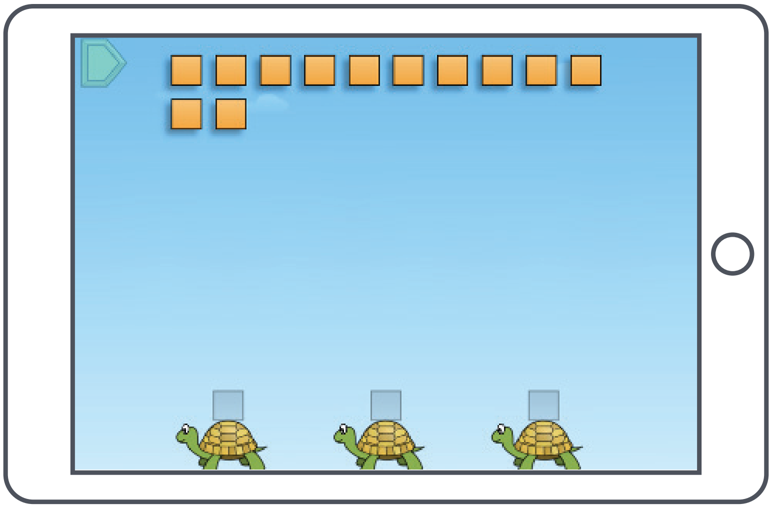
Highly accessible content

A traditional introduction to division, as illustrated by the slide below, provides a great description of the concept of division. It has a clear explanation and a picture to go along with the idea in case the words were not enough. However, for students below grade level in math – or even students below grade level in their language skills – this can be a lot to grasp and can become a barrier to accessing the content.



The basic concept of division is intuitive by nature and is something that can be grasped by any child with a handful of goldfish crackers to share evenly among friends. That's why it's so useful to introduce students to division by providing students a set of blocks or other manipulatives, and having them physically group the objects by "fair sharing."

Below is an example of an activity that introduces students to division through fair sharing in a highly accessible manner. Without any language to confuse students or even numbers presented on screen, there is little to no prior knowledge necessary for a student to engage in the activity.



Try it: [Play Fair Sharing]

The student needs to drag the squares to the turtles' backs, creating even stacks. A flat line comes down to rest on the blocks. If the stacks of squares are uneven, the ramp is not level and the little penguin cannot waddle across it. Through the animation, the students see exactly why and how the squares were not evenly divided. When the squares are divided evenly, they create a level base for the ramp and the little penguin successfully crosses the screen.

When division is presented like this, students even as young as kindergarten can engage with and grasp the concept of fair sharing – the foundation of division.

"Using ST Math to launch a new math concept allows all students to start on the same playing field regardless of their background knowledge. It facilitates conversations among students to notice and ask questions about patterns and make predictions about what might happen, as the math is the missing piece to really help students develop visual conceptual knowledge before moving on to abstract symbols in mathematics."

— Kerien Driscoll, English language learner teacher, Lowell Public Schools, Massachusetts

Create ramped learning progressions

Once concepts are introduced in highly accessible formats, it's critical to develop ramped learning progressions that transition students from the accessible concept to their grade-level endzone. To illustrate an approach to this, let's look at the learning progression for division (see below), which moves from a purely visual representation to the symbolic.

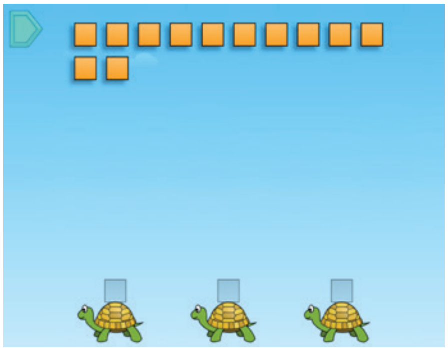
Students start with the highly accessible conceptual foundation of fair sharing – shown initially as making equal stacks of blocks on the back of each turtle.

In the next series of puzzles, students see numbers instead of boxes, requiring them to make the leap from boxes to numerals.

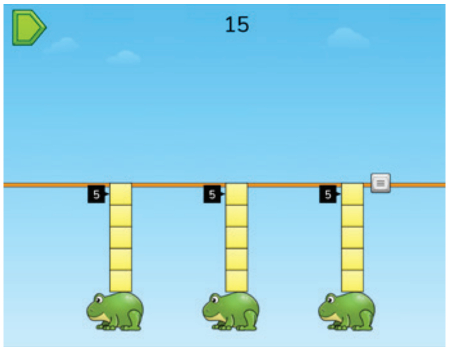
Finally, the entire division problem is presented as numbers and symbols – just as it would appear in any standard textbook or math assessment.

This progression moves students from a very accessible, foundational and visual understanding of what division is, all the way to their grade level problems, reinforcing or correcting schemas along the way.

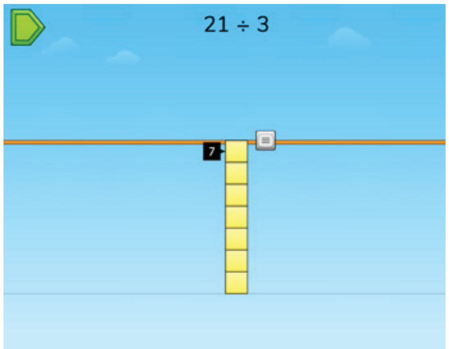
Division Learning Progression



Accessible to all



Transition to symbols



Grade level endzone

Try it: Play Fair Sharing Level 2

"ST Math is great about slipping concepts into the games gradually. A bit here and a bit there, until the full picture forms. The gradual vocabulary is great too, because often they don't know what faces or vertices mean, but that gives me an opportunity to make a connection and explain it."

— Beverly Hall, 2nd grade teacher, Putnam County School District, Tennessee

"ST Math is the best program choice for us because it aligns to our established district priorities, is accessible to all students, and keeps grade level content a priority. Its accessibility to all students was a huge selling point...because barriers such as language, the ability to hear, and/or English proficiency are non-existent."

— Courtney Davis, blended learning and MIZ coordinator,
Crowley Independent School District, Texas

Accelerate Schema-building

Schemas are the scaffolds or blueprints for our knowledge about the world around us, including objects, ideas, feelings, and series of events.

A simple schema might be: cars are a type of transportation.

A more complex schema would be: Driving a car requires unlocking the car, starting the engine, checking the mirrors, pushing on the gas pedal, turning the steering wheel, braking, and so on.

Schemas are developed, strengthened and revised through the perception-action cycle over time and typically through many different encounters with a concept. Consider a student's schema for fractions, which is influenced by numerous experiences – not all of which take place in math class.

In math, schemas help us apply existing knowledge to novel problems. Having a strong schema for a particular math concept frees up brain power to focus on developing new schemas.

Watch the video: **[What are Schemas?]**

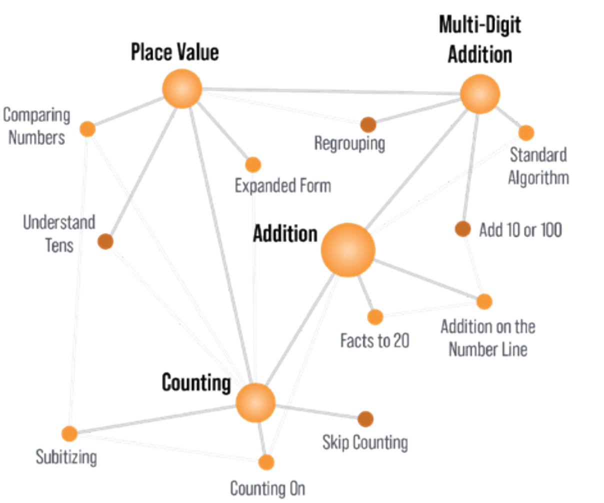
Schemas vs. Skills

Too often, learning programs look at student learning as a set of disparate skills. They then focus on identifying "gaps" in skills, and trying to fill those gaps, believing that completes their knowledge. In fact, this overlooks the deeper problem, which is often incomplete or inaccurate schemas the student has developed. Concentrating on skills, instead of schemas, is akin to missing the forest for the trees.

While we have grown accustomed to lists of skills that students are expected to master at each grade level, it can be helpful to step back and consider the bigger picture of how it all fits together.

Schemas are not singular, isolated ideas or pieces of knowledge. Instead, they are expansive, interconnected webs of knowledge that must be understood in relation to one another. This means the focus for educators needs to be on building the "tent-pole" schemas that a student needs for foundational areas of knowledge, and then connecting those tent-poles in order to create a robust schema. In mathematics, there is a clear set of core schemas students need to develop for future mathematics success: counting, place value, fractions, etc. Taking the time to build these foundational schemas, as opposed to filling in a bunch of disparate skills, is essential to accelerating learning for students.

Schemas vs. Skills



Number and Operations. Apply place value and properties of operations to solve problems.

2.1. Estimate to determine solutions to mathematical and real-world problems involving addition, subtraction, multiplication, or division.
2.2. Understand inverse relation between addition and subtraction.
2.3. Solve subtraction problems within 1,000 using strategies for regrouping.
2.4. Solve addition problems within 1,000 using strategies for regrouping.
2.5. Add 3 or more numbers for sums up to 10,000.
2.6. Apply Associative and Commutative Properties of Addition to simplify sums to 10,000.
2.7. Fluency with sums and differences within 20.

Number and Operations. Apply concepts of multiplication and division to solve problems.

3.1. Solve problems with products to 100.
3.2. Fluency with multiplication for factors to 12.
3.3. Understand that division problems can be solved as missing factor problems.
3.4. Use the Commutative, Associative, and Distributive Properties of Multiplication to solve problems.

"I used ST Math for years when I taught a 9th Grade Math Intervention class. The students who used ST Math the most consistently had the most gains in conceptual math understanding. Those gains were transferable to their Algebra 1 classes and beyond (up to and including AP Stats)."

— Erin McReynolds, math instructional coach, Milwaukee Public Schools, Wisconsin

Accelerate Math Self-beliefs

A student's own mindset is a powerful driver of math success. Students who are behind in math may be especially vulnerable to the fallacy that they are simply "not a math person." But in fact, every student has innate learning mechanisms to succeed in math.

Learning from mistakes through the perception-action cycle can foster productive struggle, a state of effortful learning that helps students develop grit and perseverance, ultimately leading them to become capable, creative problem solvers. This can be a powerful vehicle for helping students develop greater math self-beliefs. A recent study in the Journal of Research on Technology in Education found that a program focused on problem-solving and mastery-driven perseverance increased students' self-beliefs which in turn were associated with positive changes in mathematics achievement.

One way that we try to foster math self-belief is by beginning any learning progression with highly accessible problems which enable students to feel that initial thrill of success. Once students experience even a small success, this boosts their confidence and motivation to tackle the next set of problems. As they advance through the learning progression, they face increasingly challenging problems, which require more effort and, inevitably, the experience of learning from mistakes. Introducing problems within the context of a game-based learning environment has the added benefit of being a space that children typically already consider a safe space to try, fail, and try again.

As students develop not just the schemas, but the mindsets to persevere in math, they will continue to make progress not only in math proficiency on standardized tests, but in their ability to apply mathematical concepts to real-world challenges.

"I love that ST Math is accessible to all students, regardless of reading capabilities or lack of. Because it's all visual, students are able to problem-solve and determine the directions and answers on their own with minimal teacher-instruction and interaction. It makes the students more independent and active participants in their math learning."

— Katherine Murphy, teacher, Stamford Public Schools, Connecticut

"You can try again and know what math is all about. You keep trying and never give up, even when you lose [a puzzle]."

— Jeriel, 4th grader, Milwaukee Public Schools, Wisconsin

"The program gives students a chance to turn their mistakes into opportunities for reflection."

— Javier Arriola-Lopez, principal, Chicago Public Schools, Illinois

"First, in math, all of this focus on relationship building and social-emotional learning isn't an extra, teachers say. It's integral to students' academic success."

— Sarah Schwartz, Education Week

Accelerate Learning for All Students

Students who are currently performing below grade level are not the only ones who benefit when you leverage the neuroscience of learning. Accelerating feedback, accentuating schemas over skills, and giving students grade-level content is effective for all students.

Let's take a look at a few subgroups.

Students below grade level

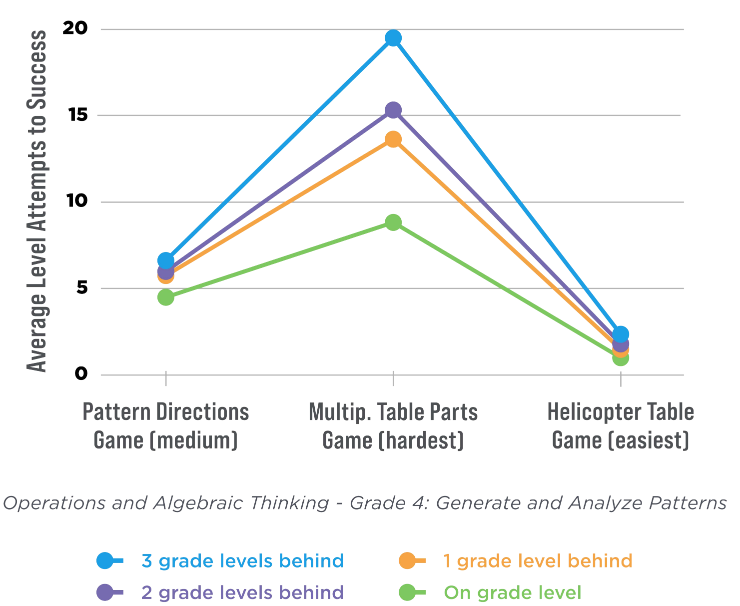
Students who are one or more years behind grade level are the primary target of most accelerated learning strategies, and have been the main focus of our attention. Much of the motivation behind accelerating learning is to bring these students up to grade level because research shows students who are provided grade-level content are more likely to meet grade-level math standards.

One thing we've learned from years of developing and providing a game-based visual math program is that while some students may require more attempts at a puzzle or game, all students are capable of conquering challenging problems with a little persistence.

As the chart to the right shows, students who are one, two or even three grades behind on math as determined by an i-Ready assessment, can enjoy the same success as their grade level peers – even if they take a few more tries at it. On "easy" or "medium" problems, students who are behind grade level may require a few more attempts – a few additional trips through the perception-action cycle, with formative feedback to guide and redirect them. Even on the hardest problems, which require multiple tries from even advanced students, those who are the farthest behind absolutely master the problem when given additional attempts.

Allowing students to go through this process, building their schemas, learning from their mistakes, and persisting through moments of struggle, not only has the benefit of moving them through their grade-level content alongside their peers, but can enhance their math self-belief.

Students at All Abilities Pass Even ST Math's Challenging Levels



Operations and Algebraic Thinking - Grade 4: Generate and Analyze Patterns

iReady assessment data

"I teach in a high-poverty, low-performing school. After just one year, our school was able to go from being an "F" school to an "C" school! We knew that critical thinking skills were missing for many students, so using ST Math was such a great fit for supporting our math goals as well as helping students develop their thinking skills. ST Math has most definitely been a big factor in our students' growth."

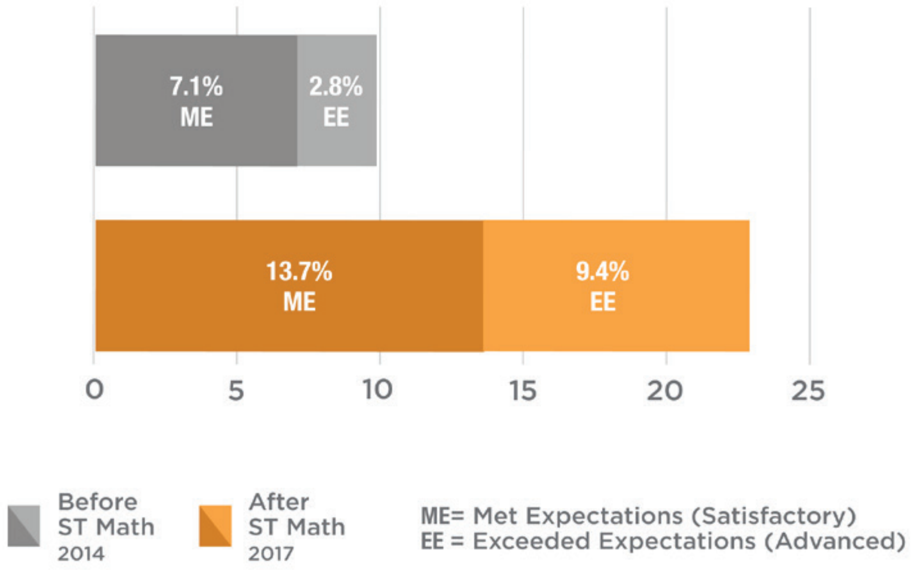
— Sarah Wilson, teacher, Granite School District, Utah

Students in special education

About 15% of public school students are classified as special education. Regardless of learning differences such as dyslexia and dyscalculia, all students learn through the perception-action cycle. Giving students in special education ample opportunities to work through problems in a feedback-rich environment, will fuel this innate learning process.

Because each student is different, some classified as special education may require more attempts at a puzzle or game, similar to below grade level students discussed above. Or, they may excel when presented with highly accessible puzzles – especially without words or other visual distractions. In either case, students in special education are capable of conquering challenging problems with a little persistence, and can especially benefit from highly accessible onramps to concepts which thoughtfully progress to grade-level content.

In fact, one of the three neuroscientists who developed ST Math has dyslexia and created the visual puzzles to focus on the core of math concepts without the distraction of words and symbols, at least in the beginning of the learning progression.



See full report

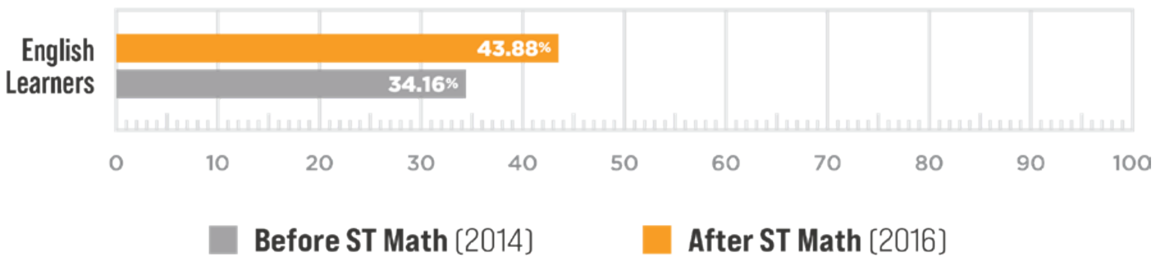
Note: For the 16/17 school year, the STAAR categories changed from 3 to 4. The proficiency levels for meeting (Satisfactory) and Exceeding (Advanced) state standards remained the same, but were renamed. In order to compare changes in proficiency levels over time, the 16/17 analysis mapped the four new proficiency levels into the three old proficiency levels as defined by the previous STAAR categories.

English learner students

All students, regardless of language proficiency level, have the ability to accelerate their math learning. However, when math is presented only as words and numbers on a page, English learner students can miss out on crucial opportunities to understand the meaning behind the math.

Focusing on presenting math concepts without language and symbols makes them highly accessible to students of all languages and language proficiency levels. Then, you can build bridges from the visual representations to the numbers, symbols and words that will be part of grade-level math and state proficiency tests.

An analysis of STAAR math tests in Texas students, grades 3-5, found that English learner students who used ST Math had greater math proficiency than similar students who did not use the program.



Percent of students meeting or exceeding standards in grades 3-5, 2014 vs 2016

"I love that my ELL students are able to solve puzzles independently. The look of accomplishment on their faces when they finish a level without me! ST Math meets the needs of my diverse classroom easily. I can do a math chat with one group and assign specific puzzles to another. The options are now endless."

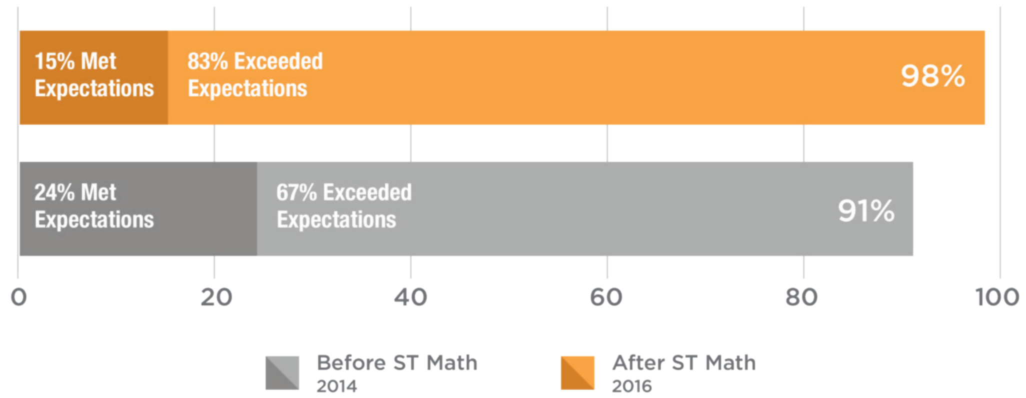
— Kristina Bartko, 4th grade math & science teacher, Sayreville Public Schools, New Jersey

Gifted students

Gifted students sometimes breeze through their school work, rarely experiencing the productive struggle that is essential to building a growth mindset and practicing persistence. It's important to give gifted students experience with challenges, and even frustration, that fuels productive struggle.

Here again, focusing on schemas and deep conceptual understanding requires students to do more than memorize a series of steps to solve a problem – something gifted students tend to excel at. Instead, it requires them to internalize schemas and apply them to non-routine problems, giving them practice at overcoming challenges, so they can thrive not just academically, but also in real life.

In fact, an analysis of ST Math students in Texas found remarkable improvements for the gifted & talented student subgroup on the STAAR test. Over a two year period, STAAR math scores among gifted students who used ST Math increased from 91% meeting or exceeding standards to over 98%.



"It's so fun! You can learn things by playing the levels. I feel smart when I beat a level."

— Christopher, 1st grade bilingual student in Milwaukee Public Schools, Wisconsin

Conclusion

Nothing above suggests that truly accelerating learning for math students is easy. If it was, everyone would be doing it, and doing it successfully.

But it is doable. As humans, as life-long learners, with growth mindsets and perseverance, we can accelerate learning, not just to recover learning loss, but to ensure that every student excels in math and in life. After the challenges of the last few years, our students deserve it, and we do, too.

Try It!
stmath.com/play

> **"I love that ST Math allows our students to develop a conceptual understanding of math topics they are already learning in the classroom. It gives all students an opportunity to problem solve through visuals and challenging puzzles, and helps build perseverance and confidence among our students."**
>
> — Tamara Yeghiayan, math coach, Hawthorn School District, California