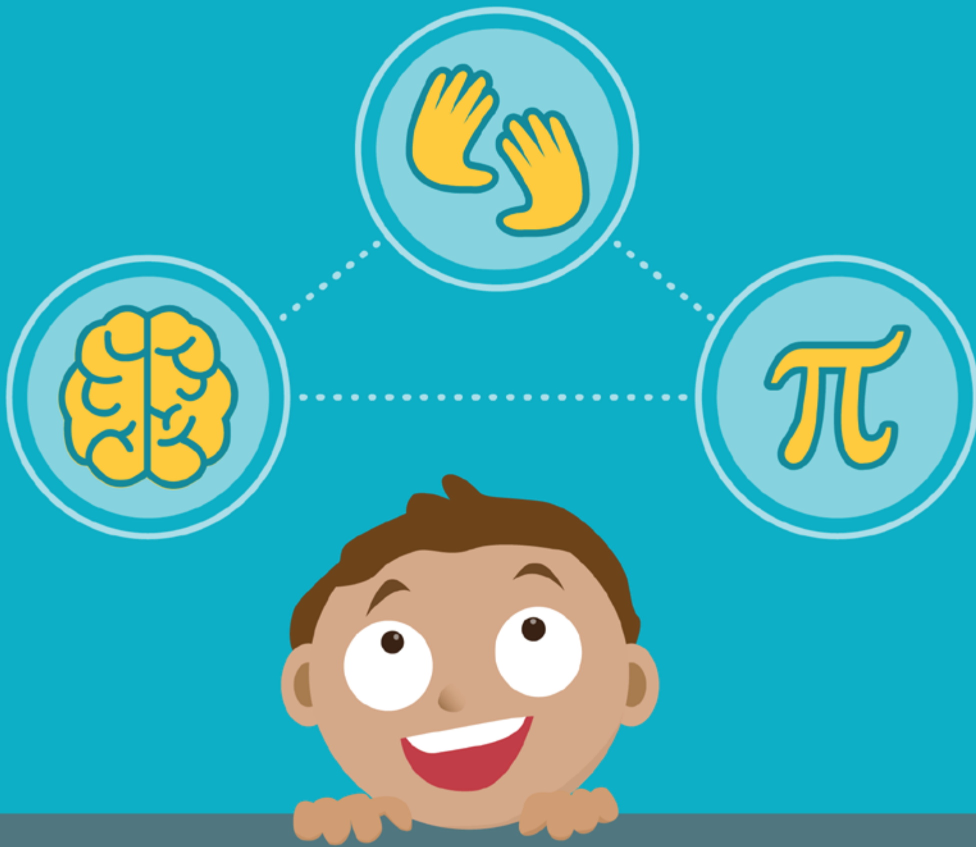
MIND-BODY-MATH

Unlocking the Power of Digital Manipulatives to Grow Mathematical Thinking



An exploration of how new technologies can be used to deliver more of the benefits of embodied cognition to today's students

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TABLE OF CONTENTS

Mind-Body Learning

The body helps the mind learn. The process by which our brains and bodies work together to learn new things is called embodied cognition. And that process has been shown to support mathematical thinking.

Research on math education — and education more broadly — has verified again and again that the physical actions of learners influence how they think, and vice versa.

A peer-reviewed article written by MIND Research Institute's psychologist Martin Buschkuehl, mathematician Brandon Smith, and education researcher Cathy Tran has taken a close look at much of that research and unpacked the relationship between embodied cognition and learning that has been evolving for decades.

Their article – and the material in this brief ebook toolkit – explores some of the ways new technologies can be used to deliver more of the benefits of embodied cognition to students growing their mathematical thinking.

This toolkit has been purposely prepared to help educators:

- Incorporate digital manipulatives in the classroom
- Design and deliver embodied learning activities, and
- Assess the learning results of such activities

We at MIND Research Institute hope you can use this material to deliver even greater student experiences and classroom learning.

Embodied Cognition and the Use of Digital Manipulatives: Defining Our Terms

What Is "Embodied Cognition"?

The concept of Embodied Cognition is built upon a decades-long branch of research into how human thinking and learning is rooted in the back-and-forth between the mind's perceptions and the body's physical interactions with the world around it. This involves a perception-action cycle in which human behaviors are the result of a series of adaptive motor responses to changes in both the external environment and internal motivations.

The body acts in response to perceptions which, in turn, create changes in the environment that are then perceived and drive further actions. This cycle continues again and again, with sensory and internal signals leading to actions, feedback, and more action. On and on it goes while — all along the way — the body is helping the mind learn, and vice versa.

What Are the Ways Learning Can Be Embodied?

These days, learning is most commonly "embodied" in the digital world through the use and measurement of:

Manipulatives. Any object a student can interact with to learn. A manipulative can be either a real-world physical thing or an object that can only be interacted with digitally by tapping it, sliding it, flipping it, turning it, or engaging it in some other way.

Gestures. Though gestures can take many forms, they are very often movements of the hand. They typically involve pointing, tracing, tapping, sliding, or cupping with the fingers or entire hand.

Whole-body Movement. Here we mean hopping, dancing, raising both hands, moving from one spot to another, etc.

This toolkit focuses mostly on the use of digital manipulatives.

What Technologies Allow Learning to be Embodied?

There are a range of emerging technologies that give learners a greater ability to interact with the world around them. And in today’s digital age, online digital environments are fast becoming a normal, natural extension of each student's physical environment. These technologies allow for learning to be more “embodied” through the use of digital manipulatives, hand gestures, and whole-body movement.

Touchscreens allow for tapping, sliding, pinching, and rotating gestures.

Sensors, like those used in the commercially available Nintendo Wii Remote and dance mats, allow for tracking of arm and leg movements.

Larger displays and **virtual reality**, whether delivered by Google’s Cardboard or other headsets, allow for a greater sense of 3D immersion.

Augmented reality, that is, seeing the world through Google Glass or with cameras projecting digital content onto real-world environments to add to what we can know in the moment, allows for layers of context and depth to be laid atop the people, places and things that fill our lives.

Each of these technologies present opportunities for building a greater level of embodiment into mathematical learning.

What Do We Mean When We Say Something Is "Embodied"?

This chart provides a generally accepted and helpful way to think about how "embodied" an experience can be with the help of technology. The degree to which a learning (or other) experience can be fully embodied can be measured across three dimensions: motor engagement, gesture congruency, and immersion.

	Level 1	Level 2	Level 3	Level 4
Motor engagement	Stationary	Stationary	Partial-body movement	Whole-body movement
Gesture congruency	• No congruent gestures • No manipulations	• Congruent gestures • Possible tangible manipulations	• Congruent gestures • Tangible manipulations	• Congruent gestures • Tangible manipulations
Immersion	Not immersive	Interaction with small screen	Motion sensors and large display	Mixed-reality with motion sensors and whole-body movement
For example:	*Observing something on a small screen*	*Interacting with a small screen*	*Interactions involving motion sensors and a large display*	*Interactions with both the physical and digital involving motion sensors to body movement*

The greater the level of motor engagement, gesture congruency and immersion by technology, the more a learning experience is fully embodied.

Generally speaking: *Motor engagement* involves moving a part or all of the body. *Gesture congruency* is the degree to which a gesture seems to naturally correspond with its meaning. *Immersion* is the degree to which you feel like you're a full participant in what you're experiencing.

A Summary of What the Research Says About Embodied Cognition and Its Role in Learning

The authors have explored decades of research into embodied cognition and how it helps people learn. Here's some of what they've found and discuss in their paper.

- Research on mathematics education has shown that learners' actions can influence how they think, and vice versa. Much of this work has been rooted in the use of manipulatives, hand gestures, and body movements and the impact they can have on learning. This is especially important given the increasing use of technology like digital touch devices, location sensors, and 3D printers for creating embodied experiences.

- Bodily movements improve retention of a learned concept by providing additional cues with which to represent and retrieve knowledge. Taking action in response to information – in addition to simply seeing or hearing it – allows for deeper levels of processing, a stronger memory trace, and a stronger ability to activate multiple ways of recalling a memory later on.

- Movement often allows learners to reduce their brain's processing power (or cognitive load), leaving more resources for other activities or cognition. For example, instead of trying to imagine how an object would appear if rotated, learners can reduce the burden on their minds by allowing their hands to do it, which frees up brain power for deeper learning.

- There is ample evidence that different aspects of mathematics are embodied in the human body. For example, the use of fingers by children to count and solve arithmetic problems is a natural example of embodied cognition in action.

- Emerging technologies are increasingly allowing learners to have a greater degree of direct interaction with both physical and digital environments, and have more immersive learning experiences.

- The measured effectiveness of digital manipulatives varies, depending on the learning outcome actually being measured. For example, the effect size of manipulative use on a student's ability to retain information seems to be greater than that on a higher-level learning outcome like problem solving. A manipulative's perceptual richness and structure also seem to impact outcomes.

Again, this is a summary of the existing body of research in the area of embodied cognition. Some educators will already be familiar with much of what's brought together in the paper. Others less so. Taken altogether, however, the research explored and summarized in the paper reinforces the importance of giving students tools that not only engage their minds, but their bodies as well. It lays a foundation for our discussion of the role of digital manipulatives in math education.

> **There is a big difference in the experience of learners who watch a teacher draw a number line on the whiteboard and the experience provided by, say, walking to different numbers on a number line drawn on the floor.**
>
> *- Martin Buschkuehl, MIND Research Institute neuroscientist*

You can download a free copy of the full peer-reviewed journal article, *Support of mathematical thinking through embodied cognition: Nondigital and digital approaches.*

About the Authors

Martin Buschkuehl, Ph.D., is Education Research Director at MIND Research Institute. For more than a decade Dr. Buschkuehl's research has been focused on improving cognitive abilities in children, as well as young and older adults. Brandon Smith is the Lead Mathematician at MIND. He is the resident expert on mathematics in the ST Math and other organizational programming. Cathy Tran is a former Design Researcher at MIND. She is now a UX researcher and continues to champion student motivation and cognition efforts.

Making the Mind-Body-Math Connection in the Digital Age

The mind-body connection is widely accepted in health and wellness, inspiring people to practice yoga or meditation and competitive athletes to seek sports psychologists. But what role does the mind-body connection play in the math classroom?

A MIND Research Institute neuroscientist, mathematician and education researcher teamed up to explore decades of research into how our bodies can help us learn math, and the ways that technology makes it easier than ever to put these powers to use in the classroom.

The following graphics presents highlights of what they found.

Learning with our bodies helps us:

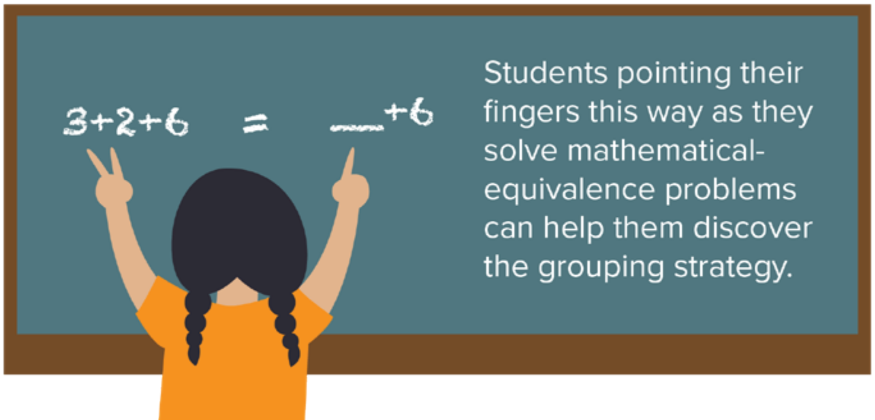
Remember what we learned

Transfer knowledge

Real-world examples

Mind-body connection in math

Using fingers for arithmetic helps students connect their real world fingers with the abstract numbers. Manipulatives lessen the cognitive load and make learning concepts easier.



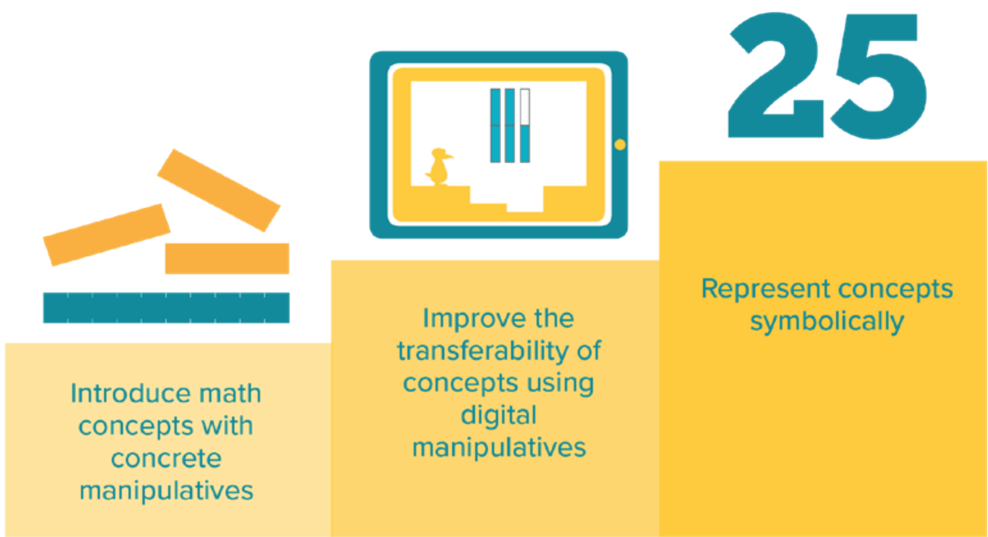
Hold! Rotate! Turn! Tap!

Why use math manipulatives?

- To develop abstract reasoning
- To interact with the math concept concretely, not just symbolically
- To allow learners to discover math concepts on their own, making it easier to later retrieve knowledge

Scaffolding with Manipulatives

How students can be guided towards mastery



From Physical to Digital

Limitations of Physical Manipulatives

- Manipulatives that are too realistic can hinder learning
- Scaling ideas like exponential growth can be difficult with physical manipulatives
- Informative feedback can be dependent upon the teacher's time, and may not be immediate

Benefits of Digital Manipulatives

- Congruent gestures (tapping, sliding and rotating) can be appropriately matched to the math concept
- Screens or virtual reality technology can provide immersive environments
- Informative feedback can be provided instantly

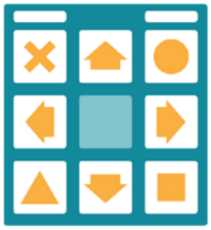
Get Moving with Technology

New ways to learn using hands and bodies

Touchscreens

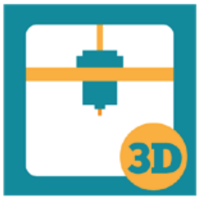
Involve gestures like tapping, sliding, rotating

Digital Sensors *(like dance mats)*



Allow full body movement

3D Printers



Produce handheld manipulatives

Both physical and digital manipulatives can put embodied cognition to work in your classroom. To maximize the benefits, carefully choose manipulatives that complement the math concept.

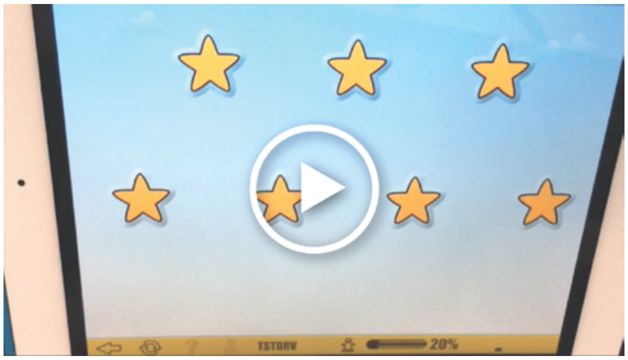
So, what are you waiting for? **GET MOVING!**

Three Ways a Touch Screen Can Help Students Succeed in Math

Fingers, blocks, pebbles and a myriad of other physical manipulatives are all tools helping students problem solve. But does that usefulness carry over when physical manipulatives give way to digital ones? The answer is a resounding yes!

In her 2011 dissertation "Do Gestural Interfaces Promote Thinking?" Ayelet Segal confirms that interactions with touch screens are effective in helping students learn. The dissertation discusses three main types of interactions that go hand in hand with digital manipulatives: tapping, sliding, and rotating.

1. Tapping



CLICK TO WATCH THE VIDEO

Because the action of tapping mimics discrete counting, it can be just as effective as counting pebbles or using fingers--even more so because a student can have unlimited taps, while he or she will eventually run out of both fingers and pebbles!

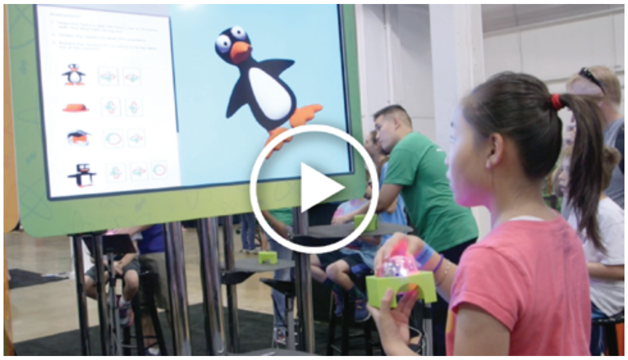
But it's essential that the taps are very closely tied to the thought process of the student. For example, tapping a screen to highlight individual pieces in an addition problem is much more effective than tapping once to highlight several pieces at a time.

2. Sliding

CLICK TO WATCH THE VIDEO

The act of sliding a finger across a screen can quite naturally represent the continuous increase or decrease of an amount, which makes it an ideal motion for helping students understand number lines or volume. Similar to tapping, making the cognitive connection between the mental model and movement is more important than the action itself.

3. Rotating



CLICK TO WATCH THE VIDEO

Rotating objects and shapes, whether in the real world or on the screen, can help students solve puzzles while reinforcing conceptual understanding and spatial awareness. Researchers have found that students who rotate shapes by sliding their finger across the screen solve puzzles with more accuracy than those who tap or click to achieve the same movement. In the video, a student manipulates a physical object which directly translates into what is happening on screen. Learning by rotating shapes, whether digital or physical (or both!), can be a great asset in learning about 3D shapes and 3D geometry.

What it all means

While tapping, sliding, and rotating can all be very effective in helping students model mathematical concepts, the most important factor is that the software they are using allows for the right gestures at the right time. Educational technology is at its best when movement naturally and directly relates to mental models.

7 Best Practices for Using Digital Manipulatives in the Classroom

Try to think way, way back to when you first stopping using your fingers to count. (No, seriously. Take a second and try. Can you get back there?)

Was it hard to stop your fingers from twitching? Did you find yourself imagining your fingers or another object in your head instead?

Research on embodied cognition explores how physical gestures and manipulatives can benefit learning by strengthening encoding, reducing cognitive load, and inspiring the use of other strategies.

Manipulatives literally allow students to play with and explore math concepts, building the neural connections that become foundational to symbolic math. With manipulatives, students have the chance to figure things out on their own.

But, our fingers (and other physical manipulatives) have limitations.

Eventually, we need to count above 10 and must discover other strategies. Luckily, we can leverage technology in many ways during the learning process. From technology's ability to provide an almost limitless number of digital fingers, to providing immediate informative feedback, educators can use technology to design embodied experiences that deliver deeper mathematical understanding.

Based on a research paper authored by Dr. Martin Buschkuehl, Brandon Smith and Cathy Tran, on the link between embodied cognition and math, here are some best practices for using digital manipulatives in your instruction.

1. Match Movements with the Mental Model of the Mathematical Concept

We can guide movements to influence thoughts in ways that improve mathematical cognition by being sure to cue the right gestures for the mathematical concept. For example:

- Tapping to add or subtract
- Sliding to estimate
- Tapping at different rates to experience the steepness of a slope

2. Make Movements Visible and Give Opportunities for Reflection

Provide real-time metrics that allow learners to observe what their body is doing and compare it to the important features of the learning objective. Immediate informative feedback is a crucial component of the perception-action cycle, showing students the effects of their actions. For example, use or incorporate:

- A playback feature with the manipulative tool
- Video recording with a phone or other device
- Screen-capture or screen-share

3. Choose Technology Tools that Won't Distract from Learning

Technology is just a tool. Like other tools in the classroom, it has the potential to be distracting and overwhelming. Pay attention to the visual and auditory effects. Are they enhancing learning? Does it provide feedback that students can use to adjust their approach? Research suggests that if the technology is too noisy with details, it will take away from the learning content.

4. Check for Logistical Constraints and Opportunities for Scale

If you've ever had to set up thirty sets of Cuisenaire rods for a particular activity, you know how challenging it can be to facilitate instruction using physical manipulatives for an entire classroom. Digital manipulatives, for the most part, are easier to scale. But even great technology has logistical limitations. Ask yourself:

- Do I have the physical space required?
- Is this something I can facilitate on my own?
- Do I have all the auxillary tools (stands, headphones, etc.) required?
- Is there enough power (from outlets, cords, or batteries, etc.)?

5. Just Because Students Are Moving Doesn't Mean They Are Learning

Just because we see the connection between the movement and the math concept doesn't mean our students will. Have some questions ready to check for understanding.

6. Track Both Learning Outcoming and Readiness to Learn

Research shows that embodied learning can provide indicators of students' readiness to learn. Gestures can reveal thoughts that learners cannot express verbally. Watch for when students' words don't match their gestures. This may indicate that their brain is starting to make the right connections.

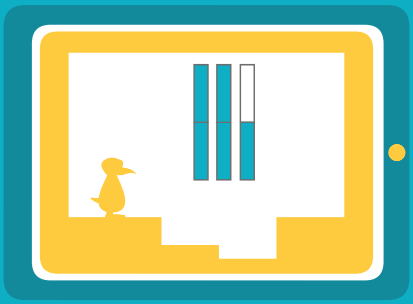
7. To Get Meaningful Insight, Keep a Record of the Process of Movements

Technology often provides the opportunity for educators to keep track of a student's movements during the learning process. Some software programs allow educators to playback and review student actions, allowing the student to actually share their thought processes and strategies. Most software will collect data over time – individually and/or in the aggregate – so educators (and students!) can track progress.

Try this:
Ask students to use their bodies to represent multiplication without physically indicating the operation. This could open a window into their thinking in a way that paper and pencil cannot. For example, a student may start small and move into a posture to get larger as a way to embody "multiplication makes things bigger."

And this:
Use a camera phone to record several different movements, and ask students to identify which ones embody multiplication. This could provide insight into student cognition that can only be gained when technology and movement collide.

Get the Most Out of MANIPULATIVES



Based on embodied cognition research, these guidelines will help you design instructional experiences for mathematical understanding.

Keep this Checklist Handy!

Educators can guide movements to influence thoughts in their students in ways that improve mathematical thinking.

Match Movements with the Mental Model of the Mathematical Concept

Providing students with the opportunity to see what their bodies are doing and make adjustments is critical.

Make Movements Visible and Give Opportunities for Reflection

While technology can be a powerful tool, it can sometimes be a distracting one.

Choose Technological Tools that Won't Distract from Learning

Even the best technologies can come with logistical constraints (like space, effort, power, extra tools, etc.)

Check for Logistical Constraints and Opportunities to Scale

Just because students are moving doesn't mean they're learning.

Have Questions Ready to Check for Understanding

Embodied learning can reveal a student's readiness to learn. Gestures can reveal thoughts he or she can't (or won't) express verbally.

Track Both Learning Outcomes and Readiness to Learn

Technology can let you keep track of student movements as they learn.

Get Meaningful Insight by Keeping a Record of the Process of Movements

Both physical and digital manipulatives can put embodied cognition to work in your classroom. To maximize the benefits, carefully choose manipulatives that complement the math concept!

**So, what are you waiting for?
Get moving!**

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Digital Manipulatives Help Facilitate Math Comprehension with ST Math

Teachers can leverage a combination of physical and digital manipulatives to support mathematical understanding in the classroom.

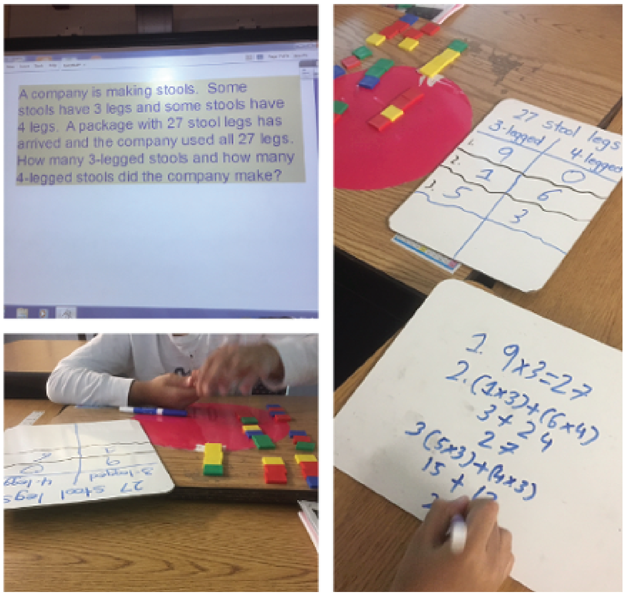
Manipulatives are any objects that students interact with in order to learn. Math educators have always relied on physical manipulatives to teach concepts to students such as pie wedges to showcase fractions, fake currency to explore the value of money, or blocks to build number sense.

With education technology becoming more common in classrooms, a new set of digital manipulatives is being used to foster mathematical understanding. Digital representations that can be slid, flipped, turned, and dropped as if they were three-dimensional objects are being used to deepen the conceptual understanding of math.

Research has shown that physical manipulatives are better to teaching tools at the earliest stages of teaching a concept, but that digital manipulatives are better for transferability. (Tran, Smith and Buschkuehl, 2017). Therefore, by connecting physical and digital manipulatives, students develop a stronger conceptual understanding by experiencing the variety of teaching techniques being presented to them.

Manipulatives in Action

Dina O'Brien, an elementary math specialist at James Madison Primary and Intermediate Schools in New Jersey, works with a diverse mix of students from across different grade levels, backgrounds, and needs. As a result, she relies on a combination of physical and digital manipulatives to teach math concepts. The variety in her teaching is key for her struggling learners.



Ms. O'Brien's student uses blocks as physical manipulatives to solve a word problem.

Besides utilizing a range of concrete manipulatives as a core component in her lessons, Ms. O'Brien uses ST Math – a learning software program that makes generous use of digital manipulatives – as a teaching and assessment tool for her "Tier 2" and "Tier 3" intervention students. It allows her to gauge their understanding of math concepts so she can better tailor her student's specific intervention needs.

Ms. O'Brien appreciates how ST Math provides personalized learning paths by adapting to each student's needs so she can target different math skills. And the immediate, informative feedback feature makes a big impact on student understanding. This feedback approach offers an intrinsically motivating learning experience that shows students the mathematical consequences of each answer they provide, in real time. With it, students can see why a solution they offered was correct or incorrect, allowing them to learn by doing.

Ms. O'Brien has seen firsthand how ST Math's virtual puzzles give students the same opportunity to make meaning and visualize math concepts as the result of their direct actions, just like any physical manipulative.

A student in Ms. O'Brien's class learning with ST Math.

Photos by Dina O'Brien

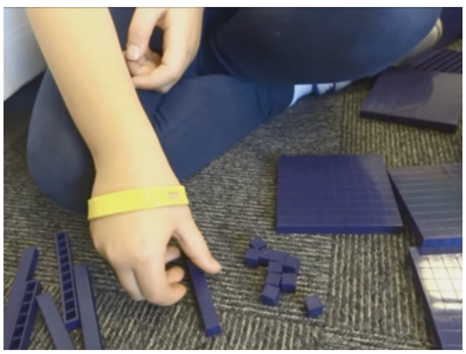
Although it is her first year using ST Math, Ms. O'Brien has already seen the impact it has made with her students. She notices that they are more engaged and motivated to learn math.

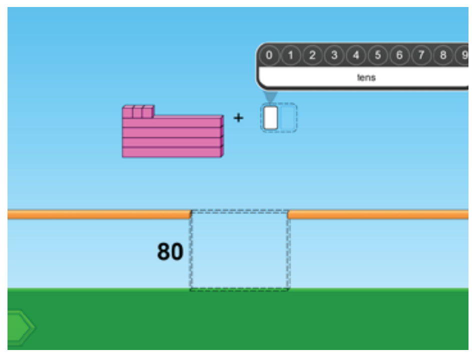
She has a rule in her classroom: never give up when presented with a new challenge! And she encourages her students to talk about the math, sharing strategies with each other to stimulate communication and math thinking.

ST Math’s Digital Manipulatives

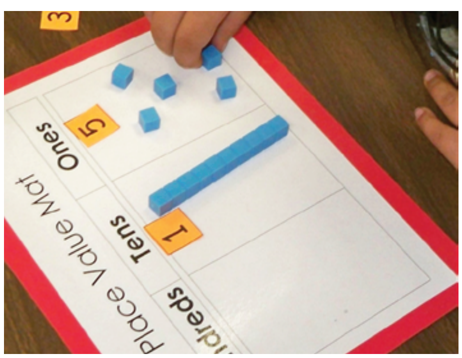
ST Math®—created by neuroscientists, mathematicians and educational innovators at MIND Research Institute—is a visual instructional program that leverages the brain's innate spatial-temporal reasoning ability to solve math problems. Here are some examples of how the ST Math PreK-8 program optimizes digital manipulatives for math comprehension. ST Math’s virtual puzzles and informative feedback give students the opportunity to make meaning and visualize math concepts as the result of their direct actions, just like any physical manipulative. Let’s take a look at some of these interactive puzzles and how they compare to other visual models and physical manipulatives often used in mathematics classrooms.

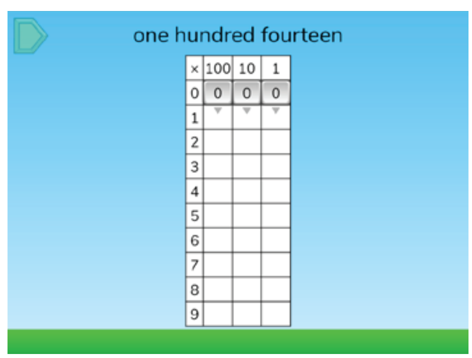
Place Value Blocks



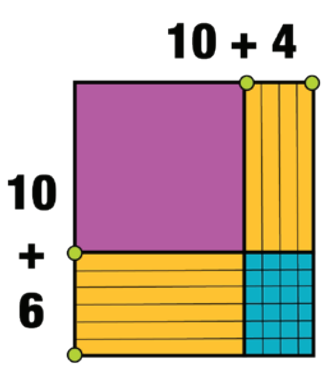


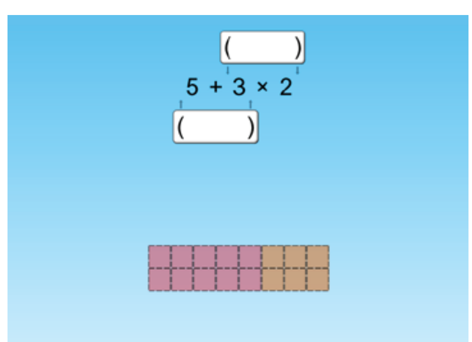
Place Value Charts



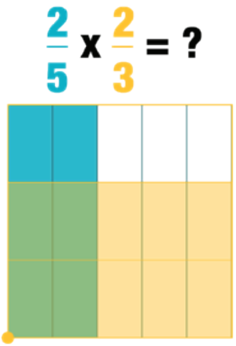


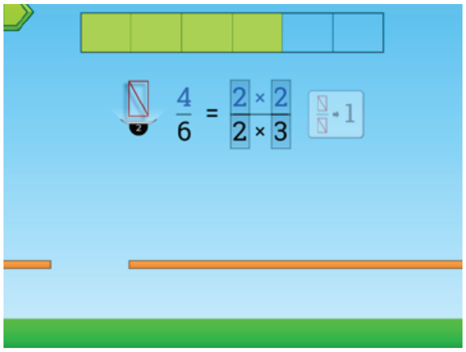
Area Models



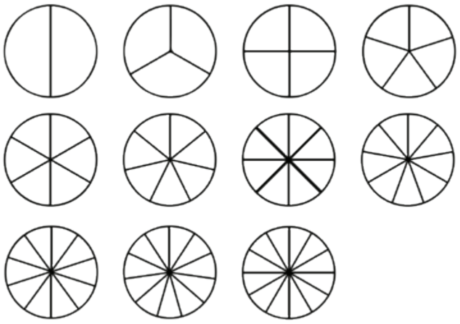


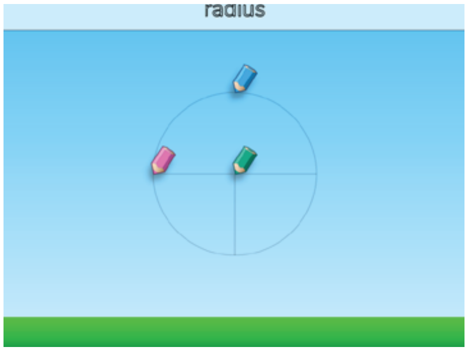
Fraction Area Models



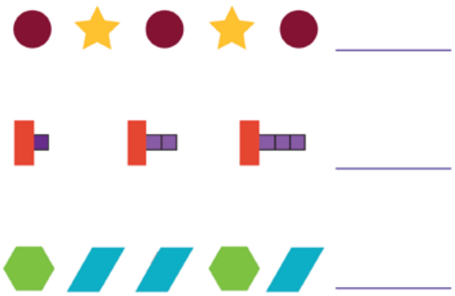


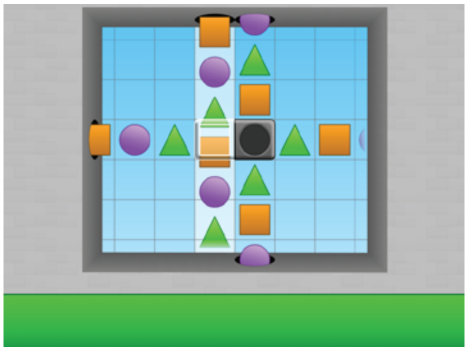
Fraction Circular Models



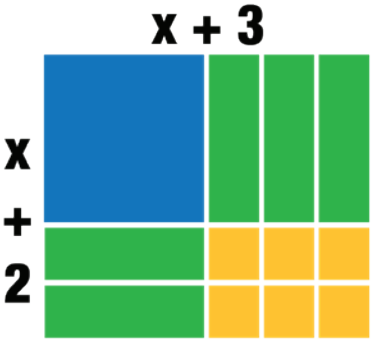


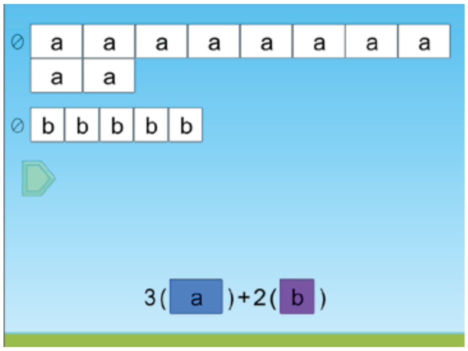
Visual Patterns



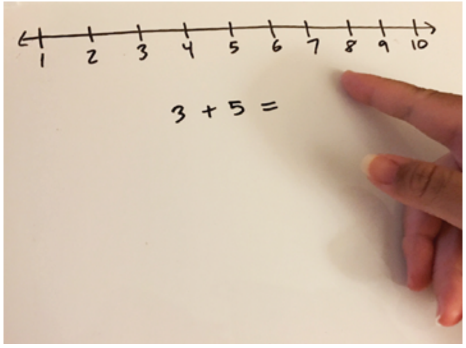


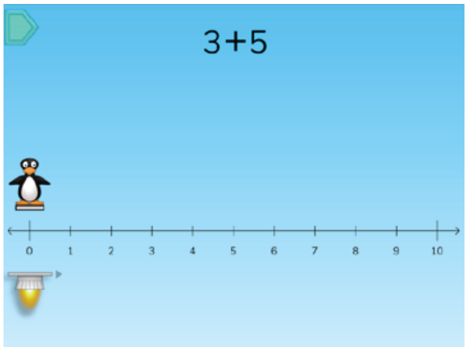
Algebra Tiles





Number Line





Unlike static manipulatives, where feedback has to come from other students or teachers, in ST Math students are able to see and interact with abstract math concepts through graphically rich digital manipulatives and receive real-time, informative feedback. ST Math's rigorous puzzles facilitate students in action-oriented learning, increasing problem-solving skills.

> **Through the use of different teaching approaches, I hope to create learning opportunities for my students so that they have the ability to problem solve and come up with alternative methods to arrive to a solution. Because of this, I see my students help one another with different ST Math puzzles, not by telling each other the answers, but by sharing their new-found knowledge. If they can teach a concept, it shows that they are understanding it.**
>
> *- Dina O'Brien, Math Specialist, James Madison Primary & Intermediate Schools, New Jersey*

Creators of the ST Math game-based learning software, MIND Research Institute supports schools and communities in ensuring that all students are mathematically equipped to solve the world's most challenging problems.

Request more information about ST Math PreK-8 visual instructional program

Request Program Information

Or go to **stmath.com**

Connect with us:

888.751.5443

info@mindresearch.org

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