BRIDGING RESEARCH AND PRACTICE

The Embodied Nature of Mathematical Learning

by Wendy L. Ostroff

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Children learn with their whole bodies, not just with their minds and brains. Such embodied cognition is especially important when it comes to learning about mathematics. Because math describes the properties, relationships, and patterns of our physical world, and because the human brain makes predictions and models in order to effectively function, mathematics forms the backbone of all of kids' emerging cognition.

Infants' and young children's full engagement with amounts, quantities, and magnitudes—as well as their ability to navigate space, and to conceptualize, manipulate, and transform objects—allows them to make fundamental sense of their surroundings. And right from birth, infants use mathematical information across a wide variety of domains—emotional, physical, and sensory—to "crack codes" and understand crucial patterns in their milieus. Biorhythms as well as music and language follow calculable orders. For example, newborn infants take statistics to achieve perception of the complex phonemic and syllabic properties of their native language (Bulf, Johnson, & Valenza, 2011). Likewise, by 6 months of age, infants discern differences in quantities of geometric figures, pictures, events, or sounds. Infants also understand addition and subtraction! In laboratory studies, when researchers add or subtract toys from behind a screen, babies expect the correct number of items to be present - and will register immense surprise if they do not add up (Cantrell & Smith, 2013).

Mathematical patterns also surround children in nature. Snail shells, sunflower petals, pinecones, and pineapples, for example, all correspond to the Fibonacci sequence, in which each measurement is the sum of the previous two. Even inanimate objects operate in mathematical ways. Planets in the solar system follow elliptical orbits, and when a kid throws a ball here on earth, it will follow a parabolic trajectory (Lewis, 2014). We can best support children's cognitive development by keeping their mathematics experience and education fully embodied.

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Finger Counting

From the time they have mastered grasping, children use their hands and arms to explore and manipulate objects, to count and make comparisons. All children—no matter what society or situation they are raised in—engage their fingers at some point for counting, adding, and subtracting. Some, like New Guineans, use the entire body surface, naming and touching their right little finger first, and then moving to their wrists, elbows, shoulders, eyes, noses, mouths, and ears: a visceral landscape of the things they have counted (Ifrah, 1985). Ancient civilizations, such as those of the Romans, Greeks, Egyptians, and Mesopotamians, used the left and right hands to indicate different place values, with the left hand representing the tens and hundreds places (Lindemann, Alipour, & Fischer, 2011). This practice fed into the invention of the abacus (the first calculator), which in effect transposed the fingers and body into beads that could be manipulated to work with even larger sums. Even the cave art of our ancestors, dated to about 27,000 years ago, shows clear and compelling evidence for the use of finger counting for integers (Overmann, 2021).

Scientific research shows that children's fine motor dexterity and spatial skills at young ages are strongly associated with their development of mathematical skills later on (Fischer, Suggate, & Stoeger, 2020; Pitchford, Papini, Outhwaite, & Gulliford, 2016). One study found that the better children were at fine motor finger skills in the first grade, the higher they scored on number comparison and estimation in the second grade (Penner-Wilger, Fast, LeFevre, Smith-Chant, Skwarchuk, Kamawar, & Bisanz, 2007). Neuroscience research using functional magnetic resonance imaging has shown that the somatosensory areas of the brain which correspond to the fingers "light up" when kids do math, even in those kids who no longer use their fingers to calculate. The finger areas of the brain were engaged to an even greater extent as math problems became more complex, involving higher numbers and more manipulation (Berteletti & Booth, 2015).

Still, many teachers have been led to believe that finger counting is immature or lazy and should be abandoned as soon as possible. Children around the world are routinely asked to not use their hands or bodies to count and do math problems in school. They are told that this is inappropriate or that it is cheating. But the cognitive science research clearly shows otherwise: children learn and master concepts of mathematics much more easily and seamlessly when they approach them in embodied ways. Our best bet for enhancing counting and number sense in children is to encourage them to use their fingers and bodies as much as possible when they engage in arithmetic.

Geometric Understanding

Children's geometric understanding and abstract mathematical knowledge emerges as they move (Bautista, Roth, & Thom, 2012). As children romp around in outdoor spaces, they engage spatially with their environments. For example, a child may enact a patterned sequence such as going up and down a tree; might gather objects with similar geometric features and arrange them based on shape and alignment; or, might construct forts using found materials and spend the afternoon adjusting their alignment, spacing, and partitioning. In outdoor play, children's bodies become the prime source for exploring and investigating problems (McCluskey, Mulligan, & Van Bergen, 2019).

Without being conscious of it, children from many different cultures and milieus use the same rhythms to display mathematical similarities and distinctions as they touch, manipulate, explore, feel, or hold three-dimensional geometrical solids. The common rhythms that children display reflect the exact geometrical properties of the objects themselves (Bautista, Roth, & Thom, 2012; Sheets-Johnstone, 2011). Researchers now believe that rhythm constitutes an essential and irreducible dimension of mathematical sense and communication. Similarly, the sounds that young children make as they interact with geometrical objects are consistent across completely different cultures, and reflect the geometrical similarities and distinctions of things that they manipulate (Bautista & Roth, 2012). In one study, a child called Nadia had an insight when sorting shapes. When the researchers analyzed video of her movements just before her epiphany, they discovered that Nadia's realization was enacted and expressed kinetically first. Her insight was observable well before she was consciously aware of the ideas that her body was enacting, and certainly before she was able to articulate the ideas verbally (Bautista, Roth, & Thom, 2012). Clearly, kids' insights are not merely features of the mind. Their knowing comes via the engagement and movements of their living bodies. In a sense, Nadia merged her body with the geometric objects in order to understand them. In a similar way, my 4-year-old nephew, Henry, was recently experimenting with the calculations of making paper boats and trying out which ones were most seaworthy in the pool. After his careful hypothesis testing, Henry explained to me which designs afforded sinking and which ones afforded floating. He spontaneously transposed his own body into the action, saying "this part stayed dry" and pointing to his shoulder, "but this part started to sink" down by his legs. Embodying his own "boatness" allowed Henry to both understand and articulate his discoveries about the geometry and physics involved. We can encourage mathematical exploration and knowing in kids when we allow them to merge with the physical world and immerse their full selves in it.

Gesturing

Kids spontaneously begin using gestures around nine months of age. Manual expressions such as clapping, waving, and pointing help children to communicate their thoughts and respond to the dynamic world. Cognitive scientists recently discovered that the movement of gesturing also helps children master complex math skills. In a groundbreaking series of studies, they instructed some young kids to gesture when they explained their solutions to challenging math problems, and others to just verbally explain the solutions. Children who were unable to solve the problems, but were in the gesturing group, tended to add new—and correct—problem-solving strategies to their repertoires. When children from the gesturing group attempted to solve difficult math problems later, they were significantly more likely to succeed than those in the non-gesturing group. This is probably because they had taken in, and then explained, their own process in a dynamic, active, multimodal manner (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007). Brain studies using fMRI have shown that children who are taught to solve math problems using gestures (instead of verbal explanations alone), are more likely to recruit the motor regions of the brain when solving future problems. Gesturing allows kids to generalize skills to new situations they have never encountered before (Novack, Congdon, Hemani-Lopez, & Goldin-Meadow, 2014). Gesturing, like finger counting and embodied geometric knowing, enables the learner's representation of a problem to be grounded in multiple brain areas, both perceptual and motor (Goldin-Meadow & Alibali, 2013; Wakefield, Congdon, Novack, Goldin-Meadow, & James, 2019). We need to encourage teachers and kids alike to engage in math using the multiple modalities of their bodies for explaining and sharing.

Children best engage with and understand math in embodied and physical ways. When we limit mathematical learning and knowing to the realm of the mind—asking kids to count in their heads, or to sit still and complete math worksheets individually, indoors—we risk greatly diminishing their full immersion into the complexity of the mathematical world. Prioritizing the mind over the body is an educational practice enmeshed in the colonial legacies of "civilizing" and "schooling" native people, and bent on controlling nature itself. If we instead configure kids' mathematical experiences and lessons as situated, whole-body endeavors, we embrace the beauty and depth, elegance and nuance, from which their cognitive skills have already evolved and developed. Young children are all set up for deep and lasting embodied mathematical learning, we just have to make sure that our educational contexts bolster and nourish it.

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