From Policy to Practice: Laying the Foundation for Future Math Success

By Ken Newbury, Deborah Wooldridge, Susan Peet, and Cynthia Bertelsen

Recent policy and research in early-childhood mathematics create an opportunity to impact the next generation of school children. In this article, a brief review and analysis of cogent research leads to a discussion of specific classroom practices and educational supports that build number sense. Through intentional practice, play, and interventions to teach subitizing and number line, all students may be "math ready" for kindergarten and first grade. The authors' goal is to leave the reader with practical guidance and strategies that may be differentiated for all learners without great expense while impacting a lifetime of mathematical achievement.

A confluence of research evidence and a rare alignment of interests around equity, early-childhood education, and urgency for national action have helped create widespread support for effective pre-K and kindergarten math education. In the midst of recent policy and research reports that create a focal point for action and funding, there is a need to examine how proposed policy and research may best translate into meaningful action in and out of the pre-K and kindergarten classroom (National Governor's Center for Best Practices, 2014). As teachers and other educators wait for increased funding and professional development, certain steps may be taken now to improve a child's mathematical future.

Get it Right from the Start

As children enter kindergarten, their future school success will be significantly influenced by the strength of their mathematical knowledge. Recent research showed that preschool children's knowledge of mathematics reliably predicted school success as late as in high school (Cross, Woods, & Schweingruber, 2009). Others corroborated this finding, noting that even after controlling for socioeconomic status, IQ, attention, and family background, a kindergartner's entering mathematic skill predicts both future math achievement and reading achievement (Duncan et al., 2007). Researchers provided hope that preschool can be a gateway to future mathematical achievement (Mullis, Martin, Foy, & Arora, 2012).

Math Equity, Math Talk, and Opportunity for All Students

A good mathematical start is important for all students but is most pressing for the poorest students in the United States. By kindergarten, children from low-income households tend to score lower in math achievement compared with their more affluent peers (Mulligan, Hastedt, & McCarroll, 2012) and tend to have the weakest number sense, a gap that persists throughout kindergarten (Jordan, 2007). A review of Head Start programs showed students made few gains after age three, and these gains were not maintained through Grade 1 mathematics (U.S. Department of Health and Human Services, 2010).

Too often, mathematics in the early-childhood classroom is relegated to a chance encounter with numbers. Limited opportunity to build early math skills across all income groups may contribute to later grade difficulties. In a national review of preschool classrooms, researchers found less than 6.7% of classroom time devoted to math (Clifford et al., 2005). In a reexamination of the large-scale Early Childhood Learning Survey—Kindergarten Class of 1998-99 (ECLS-K) study, Hamre, Downer, Kilday, and McGuire (2008) found few kindergarten teachers (28%) focused on early addition skills and subtraction. In a separate study, Engel, Claessens, and Finch (2013) observed kindergarten teachers spending 13 days or more teaching concepts that most children had already mastered, such as basic number skills, counting, and one-to-one correspondence. Such findings suggest a need to increase and carefully focus time devoted to math education for all students.

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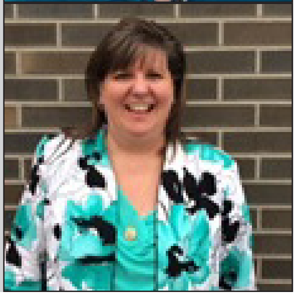


Effective mathematics education must be more intentional and directed. Classrooms that rely on free play produce lower gains in many areas (Chien et al., 2010). With limitations on classroom time and competition for instructional time with literacy and other subjects, teachers need to engage more in math talk and focused math instruction. Recent research has shown that programs intentionally targeting mathematics can improve math achievement and be maintained in later grades (Clements, Sarama, Spitler, Lange, & Wolfe, 2011). Teacher math talk can also lead to gains in preschool math achievement, including that of students from impoverished households where math talk is less common (Kibinoff et al., 2006).

The Art and Science of Teaching Math in the Pre-K and Kindergarten Classroom

Just as it is important for students to develop efficient strategies to solve math problems, it is also important for educators to develop efficient, targeted interventions to build a strong foundation of math skills in early childhood. First among the "tools" that a child needs for future math success is number sense. Although there are competing definitions of number sense, generally the term refers to a broad set of numerical competencies, including 10 identified by Powell and Fuchs (2012) and 30 specified by Berch (2005). These numerical competencies are the basic building blocks of all future mathematics and include skills such as number recognition, counting, quantity discrimination (magnitude), basic number combinations, number patterns, early addition and subtraction, and development of a mental number line. In the absence of number sense, students are often identified to have math difficulties that may persist in future years (Mazzocco & Thompson, 2005).

Researchers point to high-yield strategies that go beyond basic counting strategies and have the greatest potential for impact in the classroom. The high-yield strategies described here are selected based on their predictive power to improve mathematical achievement and the ease with which these strategies may be differentiated and implemented in the classroom with little to no cost. Among these strategies, the ability to subitize stands out as an important learning objective (Clements, 1999) that is thought to be fundamental to the development of early mathematics skill (Yun, et al., 2009). To subitize a number, a child instantly names a quantity of objects without using any physical or mental strategy. For example, when presented with three counting bears, a child who subitizes does not count but rather says, without thinking, "three bears."

In the model suggested by Clements (1999), two forms of subitizing exist: perceptual and conceptual. Perceptual subitizing is the ability to identify quickly small sets, generally between 2 and 5, with the range expanding from approximately 3 beyond 3 years of age (Gelman & Tucker, 1975). In an unpublished study, Newbury (2009) found that nearly all kindergartners could subitize 4 correctly, although students who were later identified with math concerns in first grade struggled to subitize 5. Similarly, Yun et al. (2009) assessed more than 500 kindergarten students from an urban environment and determined subitizing was a strong predictor of mathematical abilities. Others have linked subitizing skill with later math achievement (Fischer, Gebhardt, & Hartnegg, 2008).

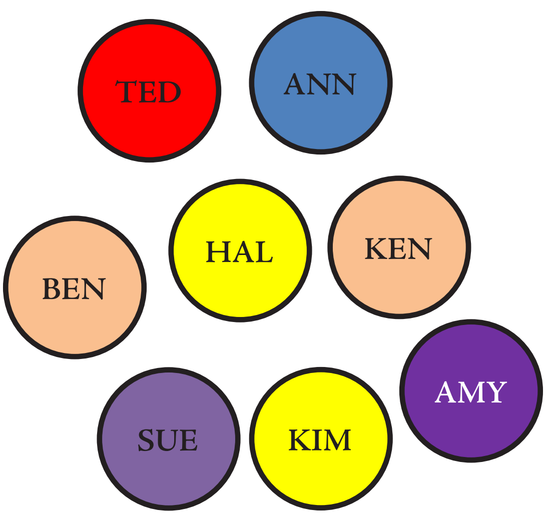
Conceptual subitizing most likely builds on perceptual subitizing and enables a student to quickly state "How many?" with quantities greater than 4. For example, a student may use conceptual subitizing to state that a cluster of 3 bears and 2 bears is 5 bears without engaging in any counting strategies. Conceptual subitizing is likely a building block for quick recall of addition facts.

Building Number Sense through Subitizing Practice and Game Play

Subitizing skill has the unique advantage of being easy to assess, monitor for progress, and scaffold. Using a variety of easy-to-find objects and a set of handmade flash cards, the pre-K and kindergarten teacher can develop a student's subitizing skills quickly by introducing challenges within a child's level of development in a game-like format. These challenges may be introduced individually, in small groups, or to the entire class.

A fun and popular example of subitizing skill to learn number combinations to 5 or more is called the "Foamie Game." In this game, students are directed to grab a specific quantity of small foam cylinders (or similar objects) as quickly as they can with two hands. The result is a variety of number combinations held in both hands that may be compared. Teachers help build skill by challenging students to find different combinations that also compose 5. In this active game, students combine perceptual subitizing (seeing numbers from 1-5), conceptual subitizing (seeing two number sets that sum to 5), and problem solving (creating different strategies to make 5). For older students or developmentally advanced students, specially marked foamies printed with the number "5" can be used to create combinations up to 10 with children as young as 4.

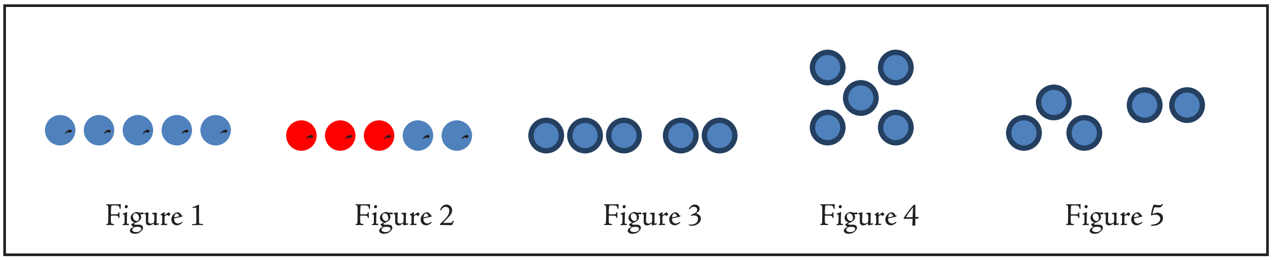
Flash cards and *subite* challenges offer additional strategies to build number sense. A *subite* challenge is a visual array of objects that may be counted in a variety of ways. For example, consider the arrangement of nametags in Example 1, suitable for first grade and beyond. In addition to telling the total number of nametags (8), students can also share their strategy for finding 8. Some students will count each circle. Others will see combinations of 2, 3, and 3. Still others will see 2 sets of 4. There are multiple ways to "solve" this challenge.



Example 1. Subite challenge.

Simple flash cards or arrangements of objects can provide equivalent challenges for younger students. For example, a child who has mastered subitizing 3 items may attempt to quickly identify 4 items without counting. This strategy should be practiced often, but for only a couple of minutes a day.

As the learner improves, the degrees of difficulty or "level" may be adjusted. Consider the four types of dot arrangements presented in example 2 for the number 5.



Example 2. Linear example for subitizing.

Note that the linear model in Example 2 is most difficult to subitize 5. Perhaps the easiest is a known shape, such as that in Figure 4, which resembles that found on a die. Figures 3 and 5 allow a student to practice conceptual subitizing (3 + 2), while Figure 2 provides a color scaffold to make it easier for a student to recognize each set of dots. As a student's skill develops, the level of challenge may also grow to include larger numbers, allowing teachers to individualize challenges for centers or small-group guided math activities.

To develop a strong foundation of number sense requires teachers to go beyond flashcards or visual displays of objects. Teachers must guide students to construct meaning at their level of challenge by presenting models represented in these subitizing challenges. In the prior example, teachers set up a center with small objects with the challenge question, "How many ways can you make 5?" In some cases, teachers may wish to allow children to represent small groups through their artwork. Learning may be extended and assessed in several ways. First, students may be asked to decompose a number into small groups. For students who are older or who demonstrate mastery, teachers may ask the student to create a simple story problem. The story problems follow multiple teacher models such as, "I found 3 seashells and my friend found 2 more. Altogether we had 5 seashells!"

Children Can Do More Than Teachers Think: Introducing the Number Line

A child's ability to place a number on a linear number line quickly and accurately has strong predictive power for math achievement at different ages and all grades (Halberda & Feigenson, 2008; DeSmedt, Verschaffel, & Ghesquiere, 2009). As children age, their dependence on a linear representation of number becomes a foundation for mathematical knowledge (Siegler & Ramani, 2009). Children who develop math difficulties and who are consequently low achieving are found to be less accurate in the placement of a number on a linear number line (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007). To place a number on a number line accurately, students must visualize a number line and understand where a number goes in the sequence. Working with number lines offers many opportunities to gain precision in the development of a mental number line and is incorporated into the National Council of Teachers of Mathematics curriculum focal points (National Mathematics Advisory Panel, 2006).

A teacher viewing a typical preschooler and kindergartner attempt a number line challenge will see the student bunch his or her numbers up near the starting point of the number line and fail to exercise equal spacing across the range of the number line. The transition from logarithmic (bunching) to linear (equal spacing) number line is a developmental process that coincides with a child's growing understanding of the number system and relative magnitude (Berteletti, Lucangeli, Pizaaz, Dehaene, & Zorzi, 2010).

Although understanding the counting sequence is a prerequisite skill, a child's ability to use accurate linear spacing develops later and may be facilitated with teaching.

The authors have had positive experience with young children accurately placing a number on a 1-5 and 0-10 three-dimensional number line. Using a wooden dowel rod with a wooden bead to represent placement of a number, these children initially conform to the original logarithmic or bunching expectation for mapping a number. An example of this bunching is seen when a child places numbers 1-5 unevenly spaced without using the full number line. However, when scaffolds are provided in the form of a background number guide with printed numbers appropriately placed, students almost always accurately place their number even after the guide is removed. Picture 1 provides an example of a child using a number line guide. The authors believe that, with practice, students internalize the visual map that models equal spacing on the number line and become successful with the task.

Opportunities to use a number line in the pre-K and kindergarten classroom require construction of a three-dimensional number line and a backing guide that spans the appropriate distance of the number line. Wooden dowel rods with knob ends and a sliding bead may be used. A pipe cleaner and sliding bead can create an inexpensive number line. Another option could be to use the plastic slide on a gallon size plastic bag as a "bead" with the width of the bag serving as the range. This activity is easily differentiated by varying the number line range, starting at 1-5 and moving to 0-10 and 0-100, or by modeling addition and subtraction facts. Advanced students can use teacher-provided number cards or playing cards to create a number line challenge. Once a card is flipped, students attempt an accurate placement on their number line and then double check against the background guide.

Boy using number line.

Guided Math Play and Games for Number Sense Development

Teachers who intentionally structure their classrooms to engage students in math-related activities and discussion provide opportunities for students to develop and master key math skills aligned to early learning standards, including counting and measurement skills, number recognition, and early addition and subtraction fluency. At the same time, guided math play, the authors' term for intentionally planned games and math play, can foster important social skills such as fair play, taking turns, and sharing. However, allowing children just to play without an intentional math focus does not provide meaningful opportunities for cognitive development or math learning (Van Horn, Karlin, Ramey, Aldridge, & Snyder, 2005).

Many ways are available to structure classrooms to engage students in guided math play. For example, in one preschool classroom an observer might see a child in the dramatic play area store counting apples for another student "customer" to promote counting skills and 1:1 number correspondence. In the same classroom, the teacher might lead a circle time or whole class through a number safari or "I Spy" game where students look for examples of a number in the classroom to promote quick visual identification of small sets of objects (subitizing). Circle time may also be used to model and teach how to play new math games or activities.

Activity centers in preschool or elementary classrooms are easily tailored to develop discrete skills such as number line development, subitizing, counting, and early fact fluency.

A wide range of games, including the authors' Foamie game and modified card games, are fun to play even as they reinforce key math abilities. In modified math card games, teachers can make their own playing cards using small sets of dots or objects printed on blank cardstock to reinforce subitizing skill. For example, instead of printing the number four, a card might have four dots or four animals; students quickly subitize the number of objects and use the card to represent "four." These teacher-made math card decks can be used to play matching games or traditional card games such as (number) fish. A student favorite may be "number war," played like the card game war, where students turn over a card from their stack and compare to see who has the highest value card. With the modified card decks, the student with the greatest number of objects appearing on the card "wins" the hand. The game may also be played to enhance a child's understanding of numerical magnitude by playing for the least or lowest card value. These games may be played independent of teacher intervention if preceded by teacher modeling and practice.

Boy participating in a counting game.

Research studies have demonstrated the importance of student's playing linear and not circular board games, such as Race to 10, to improve key components of a child's number sense (Siegler & Ramani, 2009). Specifically, as children learn to move their token on a linear game board after rolling a die, turning a card, or flipping a coin, a child's ability to estimate numbers on a number line, make numerical comparisons, count, and identify numbers improves. Linear board games are also a student favorite at centers.

Girl and boy playing Race to 10.

Informally, teachers may further encourage a child's mathematical development by providing support, asking questions, and providing interventions during complex block play. Children who engage in complex block play were shown to have better math grades and participate in advanced math classes even after controlling for IQ (Wolfgang, Stannard, & Jones, 2001). For example, using blocks as a measurement tool, the authors have guided students to measure height and length of people and objects in the classroom.

Differentiating Game Play and Parent Engagement

Most games and activities discussed here are easily modified to meet the needs of individual and small groups of learners as part of a differentiated classroom. For example, the Race to 10 may be transformed into the Race for 100 game with a 100s chart and a deck of regular playing cards. In this game, students advance their tokens on the 100s chart according to the number on a selected playing card. In this game, all face cards count as 10, providing addition practice with place value on the 100s chart. This game may also be played as a subtraction game by starting at 100 and moving toward 1 on the game board. Additionally, subitizing games, including the Foamie Game, may be modified by adding a Foamie valued at 5 or ten to increase the range and value that may be represented.

Once taught, many games such as the Race to 10 or Race to 100 and the Foamie Game may be sent home to be played with family members to further reinforce early number sense skills. In addition, a variation of the traditional Chutes and Ladders (Hasbro) game may be used to provide more board game practice at home. Although more labor-intensive, printed-card decks with simple instructions for home play provide a popular way to engage parents as math helpers while providing additional opportunities to develop children's math skills. To increase parent involvement, scheduling a math night to teach parents and their children to play math games can increase follow through for game play at home. Parents can also engage their children in challenges sent home in a "math bag" filled with paper board games, subitizing flash cards leveled to a child's ability, and counting objects.

Guided Math Play and Informal Assessment

Guided math play provides the additional benefit of opportunities to assess students' mastery of early learning standards and benchmarks. As they interacted naturally with children, preservice teachers at Bowling Green State University's Child Development Center used guided math play to assess children's mastery of early learning standards. Specifically, preservice teachers were able to measure students' proficiency with the counting sequence, one-to-one correspondence, and number recognition through play by counting steps to the door, placing small cars with labeled numbers into a matching garage, using paper clips to measure the length of an object, and identifying numbers on a pictured turtle following the reading of a classic tale about a turtle.

Math Talk and Questioning Strategies

Teachers guide their student's mathematical understanding through math talk and the questions they ask. Kibinoff et al. (2006) found the amount of math talk provided by teachers in preschool classrooms was significantly related to the development of preschooler's mathematical knowledge. Teachers can encourage mathematical thinking through modeling the way one solves the math problem by thinking out loud. Teachers can help students think more deeply about a math challenge by asking questions such as:

- *How did you figure that out?*
- *Can you think of another way?*
- *Can you teach us how you did that?*

Teachers may also ask questions with multiple solutions that help frame a student's mathematical problem-solving skill. For example, asking "How tall is the teacher?" may prompt students to consider alternative ways of measuring height. This may also lead to a discussion and inquiry investigation when students are asked, "How much taller is the teacher than Jack?"

Conclusion

Research studies and policies provide the impetus for an enhanced focus on early-childhood mathematics. With minimal time and expense, teachers can design an intentional math learning environment that fosters their students' math development through in-class games, structured play opportunities, leveled subitizing challenges, and number line work. Learning may be further enhanced through teacher math talk and engagement of parents in the development of mathematical skills for all children. In conclusion, as policy and research call for a more robust focus on early-childhood mathematics, teachers may employ simple strategies to engage students in learning activities that increase future mathematical achievement.

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