Early Predictors of Mathematical Learning Difficulties: Variations in Children's Difficulties With Math

by Michèle M. M. Mazzocco

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Recently, I asked a five-year-old neighbor of mine what she thought math was. She responded, "I don't know. I don't use math very often." Her mother, looking appropriately surprised, countered with numerous examples of the mathematical thinking used throughout their daily activities. Some of these examples have been discussed elsewhere in the *Beginnings Workshop* (e.g., Haugen & Haugen, 2003), and are not elaborated here. From this rich variety of everyday activities, adults interacting with children have many opportunities to observe children's mathematically related behaviors and to either formally or informally assess evidence of weak mathematics ability. The primary objectives of these observations and assessments are to enrich all children's mathematical thinking, and to identify children who are at risk for poor mathematics achievement.

Why is early prediction of math difficulties important?

In view of the fact that mathematical thinking permeates the daily activities of a young child, it is not surprising that mathematics also plays a role in many facets of adult life. In addition to the obvious uses in monetary transactions and many occupations (for a review see McCloskey, 2007), math influences our participation in leisure activities such as artwork, knitting, cooking, playing card games, and playing or following sports of any kind — in childhood and adulthood. Sound development of mathematical thinking enriches our everyday lives. Thus, preventing poor achievement in mathematics has wide-ranging lifelong implications.

If poor mathematics achievement during the school-age years affects outcomes in childhood and adulthood, a worthwhile goal of early childhood educators is to identify young children at risk for poor mathematics achievement. In this article, I address several factors that a person must consider in determining how to predict such a risk. The factors that I address include identifying mathematical learning difficulties, considering various sources of influence on the development of mathematical skills, and the different ways in which predictors of any aspect of development are considered accurate. Although there are no clear answers regarding how to *best* identify which preschool children are at risk for poor mathematical outcomes, findings from recent research are useful for guiding our efforts to do so. Likewise, although research has not given us all of the answers for what constitutes optimal preventative and remedial measures, early prediction will increase the likelihood that children's difficulties with mathematics will be diminished or avoided through the benefits of early intervention.

What is a mathematics difficulty?

To predict difficulty in mathematics, it is necessary to first identify how such difficulties are manifested. In other words, what it is that we aim to predict? What are mathematical learning difficulties? Are math difficulties always a reflection of a child's inherent level of ability? If not, what is to blame? When do individual differences in mathematical thinking indicate a life-long disability? Answers to these questions are complicated in part because of the many aspects of mathematics, even in early childhood (as described by Epstein, 2003); and also because the notion of a *learning disability* itself is a complicated construct. Although the field of mathematical learning difficulties is too young to provide solid answers to these important questions, we are well on our way to understanding the nature and origins of children's mathematical learning difficulties and disabilities. One finding from the research is that different children struggle with mathematics for different reasons — even if the precise reasons are not completely understood. What follows is a brief summary of some of the primary reasons for children's difficulty with mathematics. They include learning disabilities specific to mathematics, difficulties in cognitive skills related to mathematics, and influences from the environment such as schooling or socioeconomic status.

Factors associated with poor mathematics achievement

Mathematics Learning Disabilities (MLD): Approximately 6 to 10% of individuals in the general population have a persistent mathematical learning disability (MLD), or dyscalculia. There is evidence that MLD is biologically-based and has genetic influences (Petrill & Plomin, 2007). Cognitive characteristics of a child with dyscalculia interfere with successful mathematical learning. *Note that the biological basis of any learning disability does not negate the importance of early influences such as sound teaching and guidance in the early childhood setting.* However, one characteristic of children with a learning disability is resistance to the benefits usually associated with sound teaching. Children with a learning disability may need additional time or assistance, or will need modified instruction or activities, to help them acquire the skills and concepts that other children attain with relative ease. Also, children with a mathematical learning disability are more likely to show persistent difficulties over time — another reflection of not responding to environmental support such as high quality instruction. For this reason, researchers often use persistent deficiency in math test performance over time as an indicator of mathematical learning disability (e.g., Mazzocco & Myers, 2003).

If a child does not acquire a concept as easily as do other children of a similar age, it may not be due to lack of effort or intellect on the child's part. For instance, it is now well understood that many children with reading disability (or dyslexia) have specific deficits in phonological awareness and decoding skills that are evident prior to formal schooling, if assessed with developmentally appropriate measures (NICHD National Reading Panel, 2000). Rhyming words or detecting all the sounds that make up a word (b – ă – t in 'bat') are tasks that are simply much more difficult for children with dyslexia than for children without dyslexia.

In contrast to reports on dyslexia, researchers have not yet identified the primary cognitive deficits that underlie mathematical learning disabilities. However, there is evidence that children with mathematical learning disabilities lack a firm grasp on numerosity (e.g., Landerl, Bevan, & Butterworth, 2004) — understanding and recognizing quantities, or even the concept of quantity — or other basic principles that underlie counting, adding, number lines, and later on concepts like place value.

In my longitudinal research program, we have identified such indicators of mathematical learning disabilities in primary school-age children (Mazzocco & Thompson, 2005). In our studies, most children whose math scores were consistently deficient from kindergarten through third grade had failed specific basic number tasks during kindergarten. Unlike their peers who did not have mathematical learning disabilities, those with persistent difficulties were less accurate at reading numerals or at magnitude judgments (determining which of two numbers was "bigger"). These children were also less likely to correctly add small item sets even when using manipulatives. Other researchers have also reported that kindergartners' accuracy in identifying numerals and comparing magnitudes are potential indicators of poor achievement, as are difficulty in recognizing the missing number in a sequence (Gersten, Jordan, & Flojo, 2005).

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The key is that these areas appear difficult for children with poor mathematics achievement outcomes at an age when most peers succeed on these tasks. However, these skills are not necessarily the only indicators, nor would they necessarily be good indicators at an earlier age. One needs to consider the normal sequence of understanding numbers (Elkind, 2003) before determining that a child's difficulty with numerosity suggests a learning disability. There is still much to be learned about individual differences in skills related to numerosity and when individual differences actually reflect a disability, difficulty, or delay.

On the one hand, this distinction in the nature of mathematics difficulties matters a great deal; but on the other hand, a child at risk for poor mathematics achievement needs support regardless of whether the difficulties are due to a delay, difficulty, or disability. Decisions about how to support mathematical thinking in children at risk for poor mathematical achievement are guided by knowledge of what sources — other than MLD — may interfere with children's mathematical learning.

Math difficulties not limited to a specific, inherent disability in math. The notion that a mathematical learning disability has a biological basis does not mean that all children who struggle with mathematics have a learning *disability*. On the contrary, rates of failure in school mathematics (which vary depending on what mathematical skill is assessed) often exceed the reported prevalence of mathematical learning disability noted on page 41. Potential sources of mathematics difficulties include difficulties in other areas of cognition and inadequate learning environments.

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Related cognitive skills. Math involves understanding concepts of quantities and relationships between quantities, such as those that occur in mathematical operations; but it is also supported by other intellectual skills, such as language, attention, memory, and skills related to perceiving and imagining space. It is helpful to consider how these cognitive demands may challenge children faced with mathematical tasks.

Language: Words can describe absolute quantities (*one, two, or three*), categories of quantities (*many, few*), and relative quantities (*more or less*). There are words to describe relationships between amounts (*twice as much as . . .*). Sometimes words that describe a mathematical concept can be ambiguous; for example, why is 9 *greater than* 7? Sometimes the number "4" is big — (as we often remark to a four year old, "my, how big you are!"); or "4" may refer to "many" items, such as four mirrors being many mirrors for a dramatic play area; but 4 can also represent too few of something, such as if a child has four beans for lunch. Understanding these terms is linked to language development and function. Obtaining an exact answer to a math problem has been demonstrated to tap brain resources that are typically used for linguistic processing (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999). In a sense, then, memorizing math facts like 2 + 2 = 4 is as linguistic a feat as a mathematical one — sometimes more so, when the math behind the words is not understood. (In some cases, verbal recitation does not guarantee mastery.)

Spatial skills: Some of the terms used above have a spatial aspect to them; consider, for example, the terms *more* and *less*. Recognizing increases and decreases in quantities may be influenced by the ability to recognize differences in spatial configurations. For some children, the equality of ten 1-cm Cuisenaire® rods and one 10-cm block may be more visually apparent than to others. The skills involved in approximation tasks, such as estimating the number of grapes in a bowl or the approximate solution to a math problem, are believed to tap brain resources linked to spatial processing (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999). Thus it is not surprising that spatial difficulties may interfere with successful mathematics performance. Indeed, Geary (1993) proposes that one subtype of mathematical disabilities involves spatial difficulties that, for example, may manifest themselves in difficulty aligning numbers during calculation tasks.

Geary also proposes that *memory skills* can affect math performance. It may affect the ease with which children recall the procedures they are taught to carry out math tasks, such as lining up manipulatives or the mneumonics designed to assist with such recall. Although many researchers have found that math fact retrieval deficiencies are a defining feature of children with such difficulties, others stress the importance of investigating other aspects of mathematics that are challenging for these children, such as the many steps required in completing even simple arithmetic (Dowker, 2005a, 2005b). Carrying out the steps requires not only memory — remembering the steps — but the working memory needed to execute them.

Working memory, like numerosity, is a complex construct. Briefly, it refers to the deliberate review, reliance on, and application of information during a task. For example, we use working memory to guide our deliberate navigation while driving in an unfamiliar city en route to a specific destination; whereas we rely on more automatic (less deliberate) skills to drive home when using our familiar route at the end of a typical workday. When adding 7 + 4, a child must keep the numbers in mind, decide where to start counting (at "one," or at "four," or at "seven"), remember the next step (such as counting fingers or Cuisenaire® rods, as appropriate), remember how many to add to the initial number, and then remember when to stop counting. For a young child, there is much information to review ("what am I doing?"), rely on ("how do I do it?") and apply ("now I count" and "now I stop").

Deficits in working memory may interfere with children's ability to succeed in mathematical thinking even if their sense of numerosity is solid. For a child at any age, working memory is required for many developmentally appropriate mathematical tasks. It is thus not surprising that working memory and mathematical ability have been correlated, particularly in school-age children (Bull & Scerif, 2001; Mazzocco & Kover, 2007), but also in preschoolers (Espy, McDiarmid, Cwik, Stalets, Hamby, & Senn, 2004). In preschoolers, *inhibitory control* (such as waiting for a turn or waiting to respond during a task), is even more predictive of mathematical ability than is working memory (Espy et al., 2004). This is possibly because of the developmental trajectory of these different forms of deliberate behaviors.

Putting it all together. Even deceivingly simple mathematics tasks may involve many or all of these cognitive skills. Imagine counting a pile of pennies: To do so, a child must know the number words and their correct sequence, remember the sequence, keep track of which pennies were already counted, avoid distraction, and apply the principle of one-to-one correspondence. Then, if asked, "how many did you count," the child must understand cardinality to recognize the answer — but the preschooler is likely to start the counting all over when asked for the amount.

Other learning difficulties. Some of the factors associated with later poor math achievement are also associated with poor outcome in other academic areas (reading, writing, or spelling), and are thus nonspecific to mathematics. Nevertheless, math support for children with these co-occurring difficulties is certainly indicated. Still, many children with age appropriate cognitive ability overall may also have learning difficulties; these children may be among the most likely to be overlooked when predicting future outcome because of their strong performance in other areas (Taylor, Anselmo, Forman, Schatschneider, & Angelopoulos, 2000). Children with reading disability (Jordan, 2007) or attention deficit hyperactivity disorder (e.g., Fletcher, 2005) have more difficulty with mathematics than children without these conditions. This does *not* mean that all children with reading difficulties and/or ADHD will have a mathematical learning disability; however, an indictor of heightened risk can be a signal for caregivers to devote extra attention to skills and activities that promote mathematical thinking.

Mathematics Instruction. Both formal (i.e., schools) and informal learning environments have a demonstrated influence on different types of mathematical skills (Ginsburg, Posner, & Russell, 1981). Still, the role of instruction on achievement generalizes to mathematics, or at least to school mathematics (see National Research Council, 2001). School mathematics involves a curriculum that both builds on previously acquired foundations and introduces new topics. *Interrupted instruction* by a change in school, extended absence, or even a new teacher who uses different terms and strategies, may lead to difficulties for a given child at a given time. (This would *not* be an example of MLD.)

Important components of school instruction include the observation and assessment that guide teaching (e.g., Coply, 2003). Given the complexities inherent in mathematics and the number of related skills mentioned above, it seems that there are just too many ways in which things can go wrong in the development of children's mathematical thinking. Another perspective is that there are just as many ways to support children's mathematical thinking, and areas in which to observe. Astute observation serves an important role in assessing a child's "at risk" status. More than just watching, it involves establishing an environment where caregivers and children ask questions, and refining the nature, content, and delivery of the questions asked.

With regard to mathematics, looking for signs of conceptual mastery is of key importance. It is possible to learn more about what children understand about math by knowing how to observe children and what questions to ask them (Ginsburg, Jacobs, & Lopez, 1998). Even when a child's comment or answer is correct, probing for more information can be most useful.

One of my favorite explanations for why "two plus two is four" came from a child who explained it was, "because my brother is two, and I was two, but now I'm four!" (As aforementioned, recitation does not always reflect mastery.) A child who guessed my age by "measuring" my height as he inched his hand up in the air from my feet to my head gave me some insights into his concept of age.

Given the lack of widely used formal instruments to assess risk for mathematics difficulties in young children, an early childhood teacher's use of standardized probing questions may be the most informative way to gauge who is struggling with concepts that

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others seem to grasp quite readily. Moreover, teacher assessments are an important contribution to determining children at risk for learning problems, particularly at an age where formal educational testing would fail to identify problems in their earliest stages (Taylor et al., 2000).

Poverty as a risk factor. A well-established risk factor for poor mathematics achievement is poverty. This effect is true for general academic achievement as well (as reviewed by Brookes-Gunn & Duncan, 1997). The influence of poverty has been linked to the characteristics of schools in low socioeconomic status neighborhoods, and the limited resources available to families with low socioeconomic status. The resources that are limited range from adequate nutrition to intellectually stimulating environments and educated parents in the household. A child's poverty need not dictate academic outcome, as seen in resilient children who overcome these obstacles. In addition to higher intellectual ability, one characteristic of these resilient children is a close relationship with an adult other than a parent — such as a teacher (Masten & Coatsworth, 1998).

Accuracy in predicting mathematical learning difficulties requires knowledge of important risk factors.

Attitudes about math conveyed in the classroom. Some children have anxiety that is specific to mathematics. A review of the research on math anxiety is beyond the scope of this article (see Ashcraft, Krause, & Hopko, 2007), but teachers can benefit from the awareness that math anxiety can and does have negative influences on children's academic outcomes. Math anxiety is usually studied in children older than the primary school-age years, and thus little is known about its emergence.

In addition to math anxiety, attitudes about math can influence children's outcome; and if teachers can influence children's attitudes, teachers do a disservice when demonstrating a dislike of mathematics. Likewise, teachers and caregivers can promote children's mathematical thinking by reinforcing its application and its enjoyment. This notion is exemplified by a third grader in my longitudinal research who I invited to do some math activities with me one day. When asked if she would like to join me, she responded with much enthusiasm, "Oh, yes! Math is my teacher's *favorite* subject!" Although this teacher's enthusiasm for mathematics would be insufficient for remediating the skills of a child with a significant mathematical learning disability or difficulty, it evidently influenced this child's attitude about mathematics.

Math skills in boys and girls. Much attention has been devoted to the role of gender differences in mathematics achievement, such as reports of the alleged male superiority in math and the underrepresentation of females in mathematically oriented careers. Such gender differences are small, typically limited to the upper extreme ability levels, and can be secondary. Thus the gender differences that may indirectly lead females to avoid careers in science and mathematics are most likely not linked to their mathematical thinking skills in early childhood.

In my research program, we carried out a rather extensive analysis of potential sex differences in the primary school-age years, and simply did not find any areas in which sex differences persisted from kindergarten to third grade (Lachance & Mazzocco, 2006). This does not mean that the gender differences reported by others are invalid, because different studies focus on different aspects of mathematics, on different groups of children, at different ages. But, in our research, which was focused on the kinds of mathematics activities in which the average primary school-age children are regularly engaged, there was no evidence of a persistent male or female advantage in mathematical skills. These and other findings reflect why it is inappropriate for a teacher of young children to base expectations for any individual child's mathematical thinking on that child's gender, or to attribute the child's difficulty or success solely to the individual's gender.

Accuracy of predictors: Prediction and prevention

Accuracy in predicting mathematical learning difficulties requires knowledge of important risk factors. As described above, these risk factors include difficulties with numerosities and basic number concepts; difficulties in reading and attention; inadequate or interrupted education; and poverty. We must be careful how we interpret these risk factors, because not all persons with a risk factor will develop mathematical difficulties. Prediction involves multiple levels of accuracy: accurately identifying all those who *are* at risk as *being* at risk, and accurately labeling persons *at risk* only if they *are* at risk.

Where we draw the line between *at risk* and *not at risk* determines the number of false positives and false negatives that result. Obviously, we wish to avoid both.

In reality, a decrease in one typically leads to an increase in the other. If our goal is to provide support and learning opportunities for children at risk for poor mathematics achievement, we especially want to avoid inaccurately determining that someone is not at risk if in fact the child is. Yet in prioritizing the distribution of limited resources (including caregivers' and teachers' time), it is important to avoid inaccurately determining that a child is at risk if in fact the child is not.

The goal of prediction is to diminish negative outcomes; and identifying risk factors enhances this goal. If we wish to prevent poor math achievement in as many children as possible, we can:

- give children opportunities to discover attributes of numerosity
- provide a supporting learning environment for all children — specifically, an environment that includes thoughtful questioning about math — since the consequences of this approach may enrich the mathematical thinking of all children, regardless of their risk for poor math outcomes
- hone our observation skills to support children whose difficulties with mathematical thinking vacillate depending on the task demands, their ability level, and the environmental influences
- enhance our awareness of risk factors for poor math achievement and the different ways in which to support mathematical thinking, paying attention to those children who have risk factors or who demonstrate difficulties, particularly if these difficulties are manifested over time and, finally
- we, ourselves, should remember that math is a source of enjoyment at all stages of our lives, and to share this enthusiasm with the children whose development we are here to nurture.

Go to: www.ChildCareExchange.com for all the References to accompany this article.

Astute observation serves an important role in assessing a child's "at risk" status.

Using Beginnings Workshop to Train Teachers
by Kay Albrecht

Important details: Although the content of this article is complex, it holds some important details worth attending to. Work with teachers to read and reread this article for the purpose of making a list of things to look for to uncover early mathematics learning disabilities (such as understanding and recognizing quantities, identifying numerals, and comparing magnitudes, see p. 41). But, be careful. When a kindergarten example is given, work with teachers to make sure they are considering appropriate skills for younger children. When you get a good list, try it out by observing children during mathematics experiences (both child-directed and teacher-directed). Use what you learn during the observation to revise the checklist and to modify classroom practices.

Use caution: When you develop the checklist of things to look for to identify early mathematics learning disabilities, don't forget the caution that the indicators you choose be appropriate to the ages of the children. When a kindergarten example is given, work with teachers to make sure they are considering appropriate precursor skills for younger children, such as items to observe.

Read Elkind: Mazzocco references Elkind's 2003 *Exchange* article "How children build understanding of numbers." Get this article from Exchange's Article Archives (www.ChildCareExchange.com) for teachers to read as a support for considering appropriate numerosity for children under six.

The language of math: Make sure you are expanding children's math vocabulary as you do literacy and math activities. Brainstorm a list of mathematical words — make it as long as you can. Then, make sure teachers are using these vocabulary words in the classroom by observing and recording the number of mathematical vocabulary used. If the number of mathematics words is low, think about more ways to include in teachers' daily interactions with children.

Make it developmentally appropriate: The list of related skills that children must have to succeed in mathematics is long — and planning developmentally appropriate activities may be the challenge. At a staff meeting, divide teachers into small groups to come up with developmentally appropriate activities for language skills, spatial skills, memory skills, and putting mathematics all together (see p. 42-43). Use the work as a springboard to developing a large cadre of good, developmentally appropriate ways to stimulate skills.

Attitude matters!: How do teachers share their enjoyment about mathematics with children? Explore this idea with teachers to raise the level of awareness. Consider attitude in your discussion of gender stereotypes to see if some teachers need an attitude correction!

We, ourselves, should remember that math is a source of enjoyment at all stages of our lives, and to share this enthusiasm with the children whose development we are here to nurture.

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