Challenges in Identifying Target Skills for Math Disability Screening and Intervention

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Abstract

Gersten, Jordan, and Flojo (in this series) review their research on math difficulties, with an emphasis on applying current knowledge to inform practices of early identification and intervention. On a practical level, educators are in dire need of empirically based screening and intervention tools. From a scientific perspective, it is important to recognize the need to clearly define what we seek to identify and remediate, and to acknowledge that we are currently far from achieving this goal despite recent advances in the field. Among the studies reviewed by Gersten et al., as well as other studies by several other researchers, there is much variability in how mathematics difficulties are defined and measured, and even in the terms used to refer to them. I address the degree of consensus and controversy currently characterizing the state of math learning disabilities research, with an emphasis on the usefulness of a developmental perspective in appraising this young field.

Gersten, Jordan, and Flojo (in this series) review the state of research on math difficulties, with an emphasis on applying current knowledge to inform practices of early identification and intervention. Their review illustrates how different aspects of mathematical learning are understood or accepted with varying degrees of confidence or disagreement among experts in the field. Amidst the consensus and controversy that exist among researchers and practitioners, confusion naturally results when many individuals address a phenomenon that is not yet fully understood.

Studies of Mathematics Difficulties and Disabilities

As Gersten, Jordan, and Flojo (in this series) state, the study of children's math difficulties "involves various disciplines, such as cognitive psychology, child development, and curriculum-based assessment." I add to these the contributions of clinical neuropsychology (e.g., Bull & Scerif, 2001; Casey, Pezaris, & Nuttall, 1992; Cirino, Morris, & Morris, 2002; Dehaene, Piazza, Pinel, & Cohen, 2005; Fayol, Barrouillet, & Marinthe, 1998; von Aster, 2000) and behavioral neurogenetics (e.g., Barnes, Smith-Chant, & Landry, 2005; Mazzocco, 1998, 2001). Although each of these fields offers a unique perspective, each can also be approached from a *developmental* perspective. Thus, it may be useful to appraise math disabilities research in terms of three issues that guide the broader study of developmental psychology (as reviewed by Dixon & Lerner, 1999), which focus on the *sources* of development (i.e., nature, nurture, and their interaction), the *course* of development (whether it is continuous or discontinuous), and the *individual differences* that may reflect either variation in typical development or abnormalities, including deficits. The last issue leads us to perhaps the most central question of our field: What is it that develops when we speak of the characteristics of math disabilities? What skills are we identifying during screening? What are the skills that require remediation or intervention?

Gersten et al. (in this series) report that there is "enough empirical research to suggest valid screening instruments" for later mathematics difficulties. However, they go on to state that the research on valid screening instruments for math disabilities "is in its infancy" and that there are only a few studies currently devoted to this question. I agree with this latter statement, and I highlight that the key word in their initial statement, *suggest*, marks the current state of the science. For instance, in my own research, my colleagues and I have demonstrated that kindergartners *can* be effectively screened for low math achievement (e.g., Mazzocco, Myers, & Thompson, 2003; Mazzocco & Thompson, 2005), but it is not definitive *what* is measured by the screening tools determined to be most effective at identifying later math disabilities. We found that several statistical models, based on various combinations of individual test items, were quite accurate at predicting low math achievement in third grade from a prospective study. The items that we found to be most effective at identifying later math disabilities were the following items, used in combination: reading one-digit numerals, number constancy, adding one-digit numbers using manipulatives, and magnitude judgments between different one-digit numbers (e.g., "What number is larger, 4 or 5?"). These items were more informative than several alternative items, including rote counting or writing numerals. Despite identifying a key subset of test items to use for screening, it remains unclear *what* skills underlie these items that emerged as effective for screening, even if, on the surface, they appeared to tap skills such as "number sense" and "counting principles." It is also unclear whether the screening items we found to be effective when measured in kindergarten will be effective during preschool or during first and second grades. Screening items need to be considered in terms of the developmental changes in mathematical thinking that typically occur during the school years. Still, our early screening work (Mazzocco & Thompson, 2005) and that of others (e.g., Landerl, Bevan, & Butterworth, 2004) makes a preliminary contribution at identifying prerequisite skills to mastering mathematics. The findings are provocative in that they guide the direction of subsequent research and interpretations. When we identify good screening markers, it is important to recognize that other markers that are potentially as effective may also exist. The questions that remain concern what the screening markers indicate. That is, in our final analysis of how to screen for math disabilities, it is necessary to have some consensus when answering the question of what it is that *develops.* That is, what inherent difficulties, deficits, or variations manifest as a math disability, and how does this manifestation change over time?

Defining Mathematics Disability

Recently, I was interviewed by a *Washington Post* reporter preparing a story on mathematics difficulties in schoolchildren. In that article (Strauss, 2003), I was quoted as saying that we do not yet know how to define math disability. Among the many e-mail messages I received in response to my statement were several messages from parents kindly providing me with the name of someone who could give me the definition I apparently lacked. These parents assured me that their child's teacher or psychologist could give me the definition used to diagnose their child with math disability. These e-mail responses illustrate the difference between a proxy definition used in practice and a consensus definition in the research field; moreover, they were powerful reminders that many people believe that a definition is supported if it is merely used in a professional context.

Although researchers and practitioners may *intend* to address the same construct when referring to math disabilities (or a similar term), in reality, there is much variability in the characteristics of both the actual and intended groups of children described across studies and settings. There is even variation in the terms used to define study participants and, thus, the populations that participants represent. For example, Gersten et al. (in this series) emphasize their careful choice of terminology in discussing "*mathematics difficulties,* rather than *mathematics disabilities.*" A thorough discussion of this terminology was beyond the scope of their already broad review, but it is worth mentioning here as one source of confusion in the field.

Within the field, there are studies of children with *mathematics difficulties* (Gersten et al., in this series; Hanich, Jordan, Kaplan, & Dick, 2001; Russell & Ginsburg, 1984), *mathematics disabilities* (Geary, 1993, 2004), *dyscalculia* (Shalev & Gross-Tsur, 2001), and *poor math achievement* (Mazzocco & Myers, 2003). Are these terms intended to be mutually exclusive, synonymous, or overlapping? Although researchers may intend to be studying the same construct, there are important differences across studies that suggest differences in the groups associated with these terms (Landerl et al., 2004). In the discussion that follows, I use the term *MD*, which quite conveniently may refer to either *math disabilities* or *math difficulties,* as if these terms are synonymous. Later, I propose how the terms may be used to differentiate study samples and their corresponding populations.

Gersten et al. (in this series) report that children with MD "include those performing in the low average range (e.g., at or below the 35th percentile) as well as those performing well below average." Across a larger body of studies, samples of children with MD are based on children scoring in the bottom 10th, 25th, 31st, 35th, or 45th percentile. Although there is no overall justification for selecting a single cutoff as more or less correct than others, the existence of this range must be acknowledged and accounted for in both the development and application of theories guiding MD research. Additional differences across samples of children with MD stem from whether participants are unselected or preselected and from whether any additional criteria are established for study inclusion. Selection criteria may not only be present or absent, but they may vary in cases where they are present. Some preselection criteria are minimal (e.g., children not enrolled in any English as a second language programs; Mazzocco & Myers, 2003); others are more comprehensive, (e.g., children identified by their teachers as needing special education services, such as an Individualized Education Program; Fuchs & Fuchs, 2002). More frequently, samples are initially unselected and then may be classified after enrollment as typically achieving or MD. IQ score cutoffs are used as exclusory criteria in some studies, at different levels; some studies include only children with an IQ score > 90 (e.g., Fuchs & Fuchs, 2002) or > 80 (e.g., Fletcher, 1985; Mazzocco & Myers, 2003). None of these methods represents the "correct" or even the "best" or "worst" approach, as each is a valid means to gather information specific to a corresponding research question. Convergence of findings may be informative when it occurs across many study designs, yet a meta-analysis or any less formal interstudy comparison may be complicated by sources of variation across studies if those sources are difficult to tease apart. For instance, perhaps generalizations about children meeting MD criteria at one point in time will fail to characterize those who continue to meet criteria year after year.

There are several caveats to consider when interpreting and applying findings from studies using different criteria to define MD. To exemplify the influence of a single investigator-established criterion, consider the effect of using a specific standard achievement test score cutoff to establish whether a participant has MD. Reliance on standard score criteria is currently necessary in the field (as reviewed by Geary, in this series), but the information provided by these scores is limited. Children with sufficient compensatory skills may perform within the average range on achievement tests despite underlying MD. Children with primary deficits in areas other than mathematics may demonstrate secondary deficits that are indistinguishable from primary math difficulties when evaluated for MD with standardized tests. The results of a cutoff score are entirely dependent on the potential idiosyncrasies of the test being used. In our longitudinal research, we found large fluctuations at one point in time in the number of children who met criteria for MD if we used a single cutoff score with several different achievement tests. We also found large fluctuations over time in the actual group of individuals meeting criteria for MD when we used the same cutoff score (e.g., standard score at or below 86), from the same test, with the same group of children, at different grades (Mazzocco & Myers, 2003). For example, of 24 kindergartners meeting strict criteria for MD, 13 also met criteria in first grade, and 11 did not. An additional 6 children who had not met criteria for MD in kindergarten did meet these criteria in first grade. If further group differences result from using different tests and different exclusory criteria, we may find significant variation in the characteristics of children with MD across different studies.

The results of standardized achievement tests are further limited by the types of items included on the test in question. On the one hand, using a single subtest may limit assessment to paper-and-pencil calculations, word problems, or forced-choice items. On the other hand, information is also limited by a test including a wide range of problem types, but with a small number of test items per problem type (as reviewed by Geary, in this series). We have found a more normally distributed pattern of scores and greater stability in test performance over time (relative to standardized achievement tests) from a math test developed to include both formal, achievement-oriented math concepts and informal math concepts (Mazzocco & Myers, 2003). Informal math concepts and skills are those that are not learned through formal instruction but are, instead, acquired through play, observation, and other avenues for development. Informal skills such as mental addition are observed in children without formal schooling (Ginsburg, Klein, & Starkey, 1998). Not many measures are available to tap formal and informal math ability, and the measure we used, the *Test of Early Math Ability* (TEMA-2; Ginsburg & Baroody, 1990), has been developed for use only with children under 9 years of age. Tests of underlying skills are needed to at least complement if not substitute for standardized achievement tests in identifying MD.

The Nature of Math Disability

The use of cutoff scores to establish the presence of MD reflects an implicit belief that MD represents the tail end of a continuum in performance of math skills or of their development. This assumption is in line with evidence from reading disability (RD) research suggesting that RD and dyslexia are on a continuum with typical reading skills (Shaywitz et al., 1999). To some extent, evidence of continuous development and of normally distributed performance scores is supported in MD research, and in research on math skills in general. For example, Girelli, Lucangeli, and Butterworth (2000) reported that the development of automaticity in making magnitude judgments is gradual from first to fifth grade. It remains to be seen whether groups identified by different cutoff scores will differ in critical ways. In our research, we found that a similar proportion of children meeting criteria for MD in kindergarten (66%) continued to meet criteria for MD during a subsequent school year, regardless of whether their classification was based on a 10th- or 25th-percentile cutoff (Mazzocco & Myers, 2003). We continue to explore the implications of using different definitions of MD (e.g., Murphy, Mazzocco, Hanich, & Early, 2005). In the meantime, it is important to acknowledge that the wide array of criteria used to define MD will likely confound the field's efforts toward a consensus definition.

Similarly, there is a wide array of definitions for the processes or skills that are proposed to underlie MD, such as the role of executive functions (Bull & Scerif, 2001) or number sense. Although number sense is implicated as a core deficit both in our work and in that of others (e.g., Landerl et al., 2004), it is unclear to what *number sense* refers (see Berch, in this issue). It is also unclear to what extent number sense interacts with or develops independently from visuospatial reasoning (e.g., Dehaene, 1997, pp. 151–152). In our research, we found that kindergartners' visuospatial performance *alone* was as strong a predictor of low math achievement as were individual scores from both a rapid naming test (also a predictor of RD) and subtests of the *Key Math–Revised* (Mazzocco & Myers, 2003). This suggests a role of visuospatial processing in mathematical ability.

Yet when we examined statistical models predicting low math achievement, we found that including scores from the visuospatial tasks did not strengthen the predictive value of our statistically strongest regression models (Mazzocco & Thompson, 2005). There was colinearity between mathematics items and our measure of visuospatial reasoning, but insufficient evidence to understand which skills were primary versus secondary. For instance, are the processes involved in counting 13 pennies mathematical or visuospatial? Is the ability to correctly enumerate 13 pennies, scattered about in an nonuniform (nonlinear) array, related to one or more of the following skills: (a) an inherent, quantitative "number sense," however it is defined (see Berch, in this issue); (b) an accurate rote counting schema (1, 2, 3, . . . 13); (c) attention or other executive function skills that allow successfully tracking which pennies have been counted, so that no single penny is either forgotten or counted twice; (d) verbal short-term memory that enables the counter to correctly pick up where he or she left off when and if distractions occur; and so forth.

From a developmental perspective, it is not sufficient to simply know that counting a nonuniform set of 13 pennies is a good candidate for a kindergarten screening test, if we are to apply this knowledge to theory, diagnosis, or intervention. This information may be *useful* for its psychometric properties, but it does not necessarily inform us about cognitive function and development in kindergartners at risk for low math achievement. It does not help anticipate the likely indicators of MD in preschoolers, first, or second graders; develop the interventions; or know how to assess intervention success. The field of MD research is charged with uncovering and identifying the skills that *underlie* effective screening items. In this way, we can anticipate the variations of screening and identification methods that correspond to developmental changes in the domain identified as deficient among children with MD.

The Source of Math Disability

Up to this point, I have discussed the criteria and nature of MD as if all studies of MD address the same developmental observation. To some extent, my doing so is a reflection of the field. Yet there is controversy regarding the construct validity of MD as either an outcome measure or a biologically mediated developmental variation in which children achieve formal or informal mathematics abilities despite high-quality experiences or instruction. If we define MD as low math performance irrespective of its source, it is then necessary to acknowledge the additional roles of instruction, curriculum, and societal support (including factors in a child's home, school, and larger community)—factors beyond the scope of this commentary. I propose that the term *math difficulties* be used to refer to a broader group of children that includes children with or without math disability—and that *math disability* be reserved to refer to a presumed biologically based set of math difficulties, even if that basis is not yet fully understood at the neurobiological or genetic level. I am *not* proposing that these groups will be easy to differentiate, nor that there is a complete absence of any biological basis for the former group. However, I do propose that the biological basis of math disability be considered in its definition, in much the same way that the consensus definition of RD has evolved. Although the research is recent, there is evidence that mathematics performance levels are quite heritable (Oliver et al., 2004), as are aspects of RD.

Indeed, RD is now widely accepted as a genetically based disorder (e.g., Fisher et al., 2002) with neurobiologically mediated underpinnings (as reviewed by Shaywitz & Shaywitz, 2004). Knowledge of these neurobiological markers has enabled researchers to develop empirical bases for intervention (Aylward et al., 2003; Eden et al., 2004). Advances in understanding biological contributions to MD come from studying the genetics of MD and studying MD in children with known, clearly defined genetic conditions associated with low math achievement. A particularly informative outcome of the latter is the ability to compare different profiles of MD and MD correlates, corresponding to different phenotypes. For example, girls with Turner syndrome demonstrate visuospatial difficulties in recalling specific details within an array of stimuli, such as the exact location of different parts of an overall design; whereas girls with fragile X syndrome demonstrate more difficulty in recalling the overall shape of the visual array (Mazzocco & McCloskey, 2005). Overall visuospatial performance is not correlated with math achievement in girls with Turner syndrome, whereas it is correlated with math performance in girls with fragile X syndrome (Mazzocco & Bhatia, 2005; Mazzocco, 1998). Studies of contrasting phenotypes may provide evidence of MD subtypes that are not as apparent when studying more heterogeneous groups of children with MD, as well as biological contributions to MD (as discussed in more detail by Mazzocco & Gerner, 2004).

Learning From our Predecessors: RD Research

Much of what I have discussed in this commentary is similar to observations and outcomes that emerged in the study of reading disability. We can draw from RD research to partially guide the direction of research on MD. As Gersten et al. (in this series) note, much more is known about RD than about MD. They are not alone in making this comparison; indeed, there is much consensus on this notion within the field. Several of the contributors to this issue have made opening statements to this effect in articles they have published in recent years (e.g., Fuchs & Fuchs, 2002; Geary, Hoard, & Hamson, 1999; Mazzocco, 2001), as have others in the field (Cirino, Morris, & Morris, 2002; Gross-Tsur, Manor, & Shalev, 1996). This holds true for research on the genetics of MD, which also lags behind research on the genetics of RD (e.g., Alarcon, DeFries, Light, & Pennington, 1997).

One of many lessons to learn from RD research is when definitions of a disability are inconsequential. One such time comes deciding when to enhance school programs to benefit children with learning disabilities, or which children will benefit from intervention. The RD field has demonstrated how modifications to the language arts curriculum benefit readers of all levels. Thus, it is wholly conceivable that other interventions will not only benefit many (but not all) children with MD, but also typically achieving students.

Despite the advanced state of RD research, it is important to recognize that controversy still remains even in that field. There is ongoing debate regarding the roles of phonological processing (Morris et al., 1998) and morphological awareness in reading disability (Nagy, Diakidoy, & Anderson, 1993), and there are unanswered questions regarding the notion of late-emerging RD (after third grade) that is not merely misdiagnosed in the early years (e.g., Leach, Scarborough, & Rescorla, 2003). Questions remain about children whose difficulties are resistant to remediation. Such issues highlight how our path toward a consensus regarding MD will not be free of controversy, even if the controversy diminishes or shifts. Gersten et al. (in this series) have illustrated that questions about identification and intervention are among those with which the field is currently charged. These questions, along with questions about core deficits, subtypes, and biological contributions to MD, are among the many questions to be addressed by those engaged in this young and vibrant field. Through combined efforts such as those addressed in this issue, we can look forward to controversy and confusion giving rise to increasing clarity.

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