# A Review of Math Disability (MD) Literature

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## Introduction

At present, postsecondary institutions face the pressing need to review and, in many cases, reform their approach toward the teaching of mathematics. Mathematical ability is an increasingly important determinant of success within the academic world and beyond it; in a study on quantitative literacy, Rivera-Batiz (1992) asserted that after reading ability and general intelligence, mathematical fluency is the single most important factor for determining the level of success students achieve in school and their income once they complete their education.

Despite its importance, college students—particularly at the community college level—are often vastly ill prepared in terms of mathematical competency. A recent article in the New York Times reported that "the nation's 1200 community colleges are being deluged with hundreds of thousands of students unprepared for college level [mathematics] work" (Schemo, p. 1). Although the burden of this assessment falls on elementary and secondary educators, its repercussions for the community college system are clear. Additionally, our ever increasing understanding of the cognitive processes involved in mathematical thought and the many factors—psychological, cultural, biological and neuroscientific—that may affect this understanding caution against a static view of mathematical instruction.

Because of the growing number of students with diagnosed learning disabilities, it is essential that any educational reforms—if and when they are made—specifically include appropriate provisions to address the needs of these students. Woodward & Brown (2006) highlighted this need by stating that "interventions need to be continually refined to address the increasingly unique characteristics of students in special education" (p. 7).

Since prevalence statistics depend on the very definition of math disability (MD), the reliability of these statistics is often brought into question. However, extensive and frequent studies—among them those conducted by Badian (1983); Gross-Tsur, Manor, & Shalev; Kosc (1974); and Lewis, Hitch, & Walker (1994)—estimate prevalence of MD at between 4% and 7% in school-age individuals.

Regardless of the exact figure, many of the interventions intended to help students with MD would be to the benefit of all students, with or without MD. However, this does not mean that changes in teaching technique or format intended solely to improve the average student's understanding of mathematics will be sufficient for those students with MD. If these students are to be expected to succeed in mathematics, additional attention must be paid to them. Mazzocco & Myers (2005) summarized the relationship in this way: "The RD [reading disability] 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" (p. 322).

This review of the pertinent literature concerning MD will cover a variety of issues, including definition and diagnosis, possible causes, intervention techniques, and the efficacy of various tested programs.

## Difficulties in effectively addressing the needs of MD students

Although the need for effective interventions to promote mathematical learning in students with MD is clear, a number of factors make this goal particularly difficult to achieve. First and foremost, it is nearly impossible to understand the workings of MD due to a fundamental lack of understanding of the "normal" functioning of development and learning in mathematics. Geary (2005) described the manner in which this lack of understanding hinders the study of MD: "Unfortunately, in most mathematical domains, such as geometry and algebra, not enough is known about the cognitive systems that support the typical learning of the associated competencies to provide a systematic framework for the study of MD" (Geary, "Cognitive Theory," p. 306). Mazzocco & Myers (2003) pointed out that this deficiency in knowledge may stem from the cumulative nature of mathematical development, especially in the elementary years.

In addition, the first step towards aiding students with MD is identifying them as those needing special assistance. Since many students who may qualify as learning disabled are often not identified until they reach college (or at all), ensuring that their needs are met is a particular challenge (McGlaughlin, Knoop, & Holliday, 2005). This problem is furthermore related to the utter lack of consistency in definitions of MD, a topic that will be discussed in detail below.

These difficulties are compounded by the absence of appropriate research conducted on MD, particularly when compared to the amount of studies dedicated to understanding reading disability (e.g., Rasanen & Ahonen, 1995). Swanson & Jerman (2006) described math disability research as in its "early developmental stages" (Swanson, p. 270). Maccini & Gagnon (2006) noted that there existed no studies addressing "empirically validated and recommended instructional practices to assist secondary students" with MD (Maccini, p. 219).

The relative silence of the scientific community is especially noticeable in regard to the lack of research conducted specifically on MD in postsecondary students. In their review of twenty-three studies, Bryant & Dix (1999) only found two that focused on algebra. In point of fact, the majority of studies are concentrated on arithmetic computation (Mastropieri, Scruggs, & Shiah, 1991). According to McGlaughlin, Knoop, & Holliday (2005), "empirical evidence for effective interventions for postsecondary students is, at best, scarce" (McGlaughlin, p. 225).

As alluded to above, an agreed-upon definition of MD has proven to be elusive (Mazzocco & Myers, 2003; Swanson & Jerman, 2006). Mazzocco (2005) indicated that not only are the definitions and measurements of MD inconsistent, but the terminology is likewise erratic (i.e., *mathematics difficulties* vs. *mathematics disabilities*). This variation in definitions necessarily complicates the design and implementation of effective interventions.

Another element that presents a challenge is the complex and varied nature of mathematical understanding, and therefore of MD. Batchelor, Gray & Dean (1990) have shown that arithmetic performance is affected by a variety of verbal and nonverbal neuropsychological factors. It is fair to assume then, as is discussed below, that students with MD can have deficits in any one of these specific areas or in a potentially endless combination of them. Furthermore, mathematical performance has been linked to affective factors, such as math anxiety (Ashcraft & Ridley, 2005), which indicates a need for a holistic approach when helping students with MD. The infinite possible interactions between these areas reveal the need for an approach to intervention that is tailor-made for each student.

Although these factors represent an impressive obstacle in effectively addressing MD, the necessity to do so is clear. Fortunately, the research, though it may be limited, does present some important conclusions.

## Defining MD

"In the field of MD, work toward establishing a consensus definition is in its early stages" (Mazzocco & Myers, p. 219). Indeed, many of the relevant studies point to a need for consistent definitions, criteria and testing (e.g., Fuchs, et al., 2005; Geary, 2005). On the one hand, there is little debate about the most basic standards, particularly the requirement that the student in question be of at least average intelligence. Of course, the question then becomes how one defines and quantifies average intelligence. This is beyond the scope of this analysis, but should be noted as an example of how difficult standardization of MD diagnosis can be. It is clear, however, that students must at least be diagnosed as having a learning disability according to whatever established federal, state, and institutional guidelines apply (e.g., Title V regulations).

Various researchers have identified general features of MD and what specific manner of problems tend to be the most difficult for MD students. Nolting (2000) asserted that most students with LD will show average abilities in arithmetic, but will be unable to learn algebra without assistance. He believes that students therefore often learn to compensate for their disability, often going undiagnosed until reaching college, where self-taught strategies cease to work. According to Nolting's research, trouble with multi-step problems and browning errors are the two best methods for predicting MD. Dehaene & Cohen (1991, 1995, 1997) researched the neuroscientific base of math disability and believe that inaccurate retrieval of arithmetic facts is related to abnormal functioning of the left basal ganglia, the thalamus, and the left parieto-occipito-temporal areas.

Sometimes, math disability is defined as a single entity with various deficits. In these cases, it is most commonly referred to as dyscalculia or developmental dyscalculia. Kosc (1974) defined it in broad terms, stating that dyscalculia has its basis in a genetic or congenital disorder that affects the specific parts of the brain involved in the development of normal mathematical ability. Recent research (Oliver, et al., 2004) illustrated the genetic basis for mathematic ability. Kosc also divided dyscalculia into two categories: practognostic dyscalculia and ideognostical dyscalculia. According to his differentiation, practognostic dyscalculia involves difficulty with the manipulation of objects, either real or mental, during mathematical work. People with ideognostical dyscalculia, on the other hand, have trouble connecting mathematical concepts to allow for calculation. It should be noted that dyscalculia is often confused with acalculia; the difference between the two being that acalculia is the direct result of brain damage.

Mahesh Sharma (1986) also chose to divide dyscalculia into two groups: quantitative and qualitative. In this model, quantitative dyscalculia involves difficulty with sequential directions and spatial organization, whereas qualitative dyscalculia is characterized by problems with inductive and deductive reasoning, estimation, pattern recognition and/or visualization.

Various elements of college mathematical curriculum prove to be difficult for students with dyscalculia, including timed tests (Landerl, Bevan, & Butterworth, 2004) and higher-level reasoning (Sullivan, 2005). Nolting (2000) also suggested that some students' math disability may only be related to a particular mathematical domain, specifically referring to dysalgebria and dysgeometria.

It is clear that even when mathematical disability is defined as a single entity, a variety of subgroups become necessary to further qualify the problems that an individual student has. For this reason, the majority of researchers choose to define MD as a composite disability and highlight various cognitive areas where problems have been identified in students with mathematics difficulty or disability. These areas differ depending on the model, but they often overlap or are interconnected. Judging by the complex nature of mathematical thought, it is a distinct possibility that all of these elements are involved.

In their recent study on college students with MD, McGlaughlin, Knoop, & Holliday (2005) concluded that the most significant contributors to these students' difficulties were working memory, mathematical fluency, reading comprehension, and visual/spatial/nonverbal weaknesses. Other researchers specifically mention some of these elements and others are related or affected by areas included in different models.

One of the most commonly referenced models is that of Geary (1993), which divides MD into three categories: semantic retrieval, executive-procedural and visuospatial MD. In this model, semantic memory MD is characterized by difficulty in retrieving mathematical facts and variation in response time. People with procedural MD have more conceptual difficulty, involving problems with strategizing, execution, and the acquisition of mathematical concepts. Finally, visuospatial MD, the least understood of the three (Mazzocco & Myers, 2003), is identified by sign confusion (x vs. +), improper numerical alignment, or any other difficulty visually processing numerical information incorrectly and then presenting in similarly.

Cirino, Morris & Morris (2007) recently tested the efficacy of using Geary's three categories to predict MD among 337 college students. They found that "overall predictive power for [calculation and mathematical reasoning] was high," but also alluded to the possibility that other cognitive factors may be involved (Cirino, p. 103). They concluded that these factors had the same ability to predict MD in college students as they did in children, which is significant, considering that the majority of studies on MD focus on younger children and not adults.

Nolting (2000), in his work with college students with MD, proposed another model that is supported by other research (McGrew & Hessler, 1995; Batchelor, Gray, & Dean, 1990; McGrew, 1994; Meyers, 1987; etc.). In this model, students' specific cognitive deficits, in combination with their content problem (e.g., algebra), are used to further categorize their specific difficulties. For example, "a student may have dyscalculia with a visual processing speed deficit" (Nolting, p. 27). In his model, the cognitive clusters tested on The Woodcock Johnson Psycho-Educational Battery – Revised: Test of Cognitive Ability (WJTCA-R) (Woodcock & Johnson, 1989) were used to differentiate specific areas where a student with MD may have problems. These clusters are: processing speed, auditory processing, visual processing, short-term memory, long-term retrieval (working memory), comprehension-knowledge (long-term memory), and fluid reasoning. Fluid reasoning was found to have the highest correlation to mathematical performance, but it remains unknown how students can improve in this area (Hessler, 1993; McGrew, 1995). This points again to the need for further research in the understanding of MD and successful interventions.

One area that has received particular attention in the literature is memory, specifically short-term memory. Nolting (2000) divided memory into eight stages (sensory input, sensory register, short-term memory, working memory, long-term memory, abstract reasoning and memory output) and asserts that MD can affect any one of them. In their comparison study between children with and without MD, Swanson & Jerman (2006) observed significant differences in performance between the two groups when testing verbal working memory, visual-spatial working memory, and long-term memory. They found that verbal working memory was the main cognitive factor differentiating MD students and their non-MD peers. In their study on the arithmetic word problem solving of children, Passolunghi, et al. (1999) found that MD children had deficits in working memory, but not short-term memory. Geary & Hoard (2002) also underlined the importance of working memory, proposing that it may be the central deficit of MD.

Nolting (2000) stated that working memory is especially important in math since mathematical problem solving often involves multiple steps and keeping track of different information throughout the full process. Also, if students have difficulty memorizing arithmetic facts (such as the multiplication table), they will have to dedicate more working memory to computation, leaving less available for more complex problem solving. This is particularly evident in higher-level math, but can be seen even in children with MD learning to count (Carr & Hettinger, 2002).

Levine (1999) specifically tried to isolate the deficits involved in higher-level math (algebra and calculus) and has indicated that the following areas seem to be most involved: "poor abstract concept formation; memory deficits; language problems, especially learning and remembering new vocabulary; poor visual and paired association memory for new forms of notation" (Levine, p. 415).

Clearly, there is much debate about which specific processes are involved in mathematical learning, which of these are most important, and which are most likely to prove difficult for students with MD. Furthermore, the varying criteria by which MDs are judged means that, depending on one's perspective, all students of at least average intelligence but under a certain level of achievement in math can be defined as having

MD without the presence of other mitigating factors (e.g., quality of education). In this case, the occurrence of MD will therefore depend on how a low level of achievement may be defined. Indeed, Mazzocco (2005) found that depending on the study, children were included as having MD if they scored below the tenth, twenty-fifth, thirty-first, thirty-fifth, or forty-fifth percentiles.

Mathematics is a difficult subject for many students, and most students have varying strengths and weaknesses within it. Therefore, regardless of what numerical limitations one might place on test scores in order to determine underachievement, those underachieving students in mathematics can surely benefit from the techniques, strategies, approaches, and programs that are beneficial to students who can be meet the criteria of MD using a strict definition.

Still another complication in indicating precisely what constitutes MD is the affect that other learning disabilities have on mathematical performance and the role of co-morbidity. Because the demands of mathematical thought are so varied, problem-solving is often affected by other learning disabilities. According to Light & DeFries (1995), more than sixty percent of students with learning disabilities had notable difficulty in mathematical performance.

Reading disabilities, particularly dyslexia, have been shown to negatively impact mathematics achievement (e.g., Miles, et al., 2001). Unsurprisingly, studies show that co-morbid individuals (students with RD and MD) often perform worse in mathematics that any other group (Jordan & Montani, 1997; Fuchs, et al., 2004; Swansons & Jerman, 2006). This is important considering that Mazzocco & Myers (2003) found that fifty percent of students with MD also had RD. There are a variety of explanations for this. Firstly, since word problems are extremely common in mathematics classes, students with reading difficulties will have increased difficulty (García, et al., 2006; Lucangeli &

Cabrele, 2006). Secondly, memory representations for arithmetic facts have been linked to the same memory systems as reading comprehension (Geary, 1993, 2003). Finally, mathematics development requires learning a whole new vocabulary and, as Levine (1999) stated, "as might be expected, students who struggle with semantics in other settings may be confused by mathematics vocabulary" (Levine, p. 405).

A link has also been established between ADHD and mathematical difficulties. Lucangeli (2006) found that "students with ADHD-Predominantly Inattentive Type may be at increased risk for arithmetic calculation deficits" (Lucangeli, p. 60). It has been asserted that the primary reason students with ADHD have a higher chance of struggling with mathematics is that those with ADHD have particular difficulty attending to relevant information (Zentall, et al., 1994). This deficit can be particularly damaging in problem solving, since poor problem solvers remember less of what is relevant to a problem solution and more of what is irrelevant (Passolunghi, et al., 1999). Fuchs, et al. (2005) proposed that not only is MD affected by attention, but that MD can in turn indirectly affect attention. "Classroom instruction may fail to address the needs of children with poor math potential, determined by other deficits, and this mismatch between needs and instruction creates poor attention" (Fuchs, p. 510).

Evidently, more research must be done before agreements on more consistent and formulaic definitions of MD and its subtypes can be reached. Judging by the complexity of the processes involved and the immense variety of deficits an individual can have, a one-size-fits-all set of criteria may never be established, nor would it be tremendously helpful. However, while different research may emphasize different deficits or models of deficits, many of the cognitive areas implicated are the same. Thus, while waiting for research to validate one model over another, institutions can proactively and effectively begin to address MD.

**Testing for and identifying MD: two models**

Stemming from the disagreement over the deficits involved in MD, the literature shows a parallel debate about the most appropriate method of testing for mathematics disability, with the two major camps being those that favor a discrepancy-based model and those that argue for a response-to-intervention model. Discrepancy-based models use a substantial difference between: (a) aptitude and achievement, (b) different cognitive abilities, or (c) achievement at different academic levels. Mather (1991), Hessler (1993) and McGrew (1994) have asserted that the efficacy of using these indications as documentation for a learning disability and a majority of the pertinent research uses a discrepancy-based model to determine who meets the criteria for MD and who does not for their studies. Nolting (2000) has strongly advocated this approach and believes that results from the WJTCA-R are the best indicator of these three types of discrepancy.

More recently, researchers, led by Fuchs, et al. (2005), have proposed using a response-to-intervention model. This model is based on the belief that appropriate intervention eliminates all mitigating factors involved in mathematical performance. In this model, if a student fails to respond to intervention in a manner similar to most other students, the student is thus believed to have a mathematical disability. Fuchs, et al. assert that the first—and most common—type of discrepancy-based identification "which relies on a discrepancy between intelligence and achievement, has been discredited" (p. 493). Several studies (Brackett & McPherson, 1996; Greg, McKinley & Johnson, 1996.

Mather, 1991) also indicated that this technique may be problematic when used to test adults.

The question of what testing and identification techniques are appropriate is an important one, especially for community colleges where those identified as MD are entitled to “empirically validated instructional practices that help them succeed” (Maccini 218). It is of the utmost importance, therefore, that these institutions follow this theoretical debate, thereby ensuring that their institutional policies for MD and their very identification methods are as effective as possible.

**Psychological and affective problems associated with MD**

More and more, research has indicated the important role of emotion and psychological well-being in learning. According to Marzano’s Dimensions of Learning Model (1992), without the proper attitude toward learning, real learning cannot be achieved. Nolting (2000) pointed out the correlation between non-cognitive factors-such as low motivation and poor attitude—and their cognitive consequences. McGlaughlin, et al. (2005) connected this idea specifically with mathematics: “the level of math fluency can […] be negatively impacted by inattention, depression, and high or low degrees of anxiety” (McGlaughlin, p. 229). This is especially damaging in the case of students with MD who naturally possess “poor self-conceptions” (Montague & Garderen , p. 438).

Students with MD are particularly prone to suffering from learned helplessness, which impedes the ability to learn math, since low self-conception will affect effort and thus, decrease overall learning (Montague, 1997; Montague & Garderen, 2003). These psychological and emotional factors inhibit students with MD from attempting work they would otherwise be capable of because they view the task as too difficult or lack the necessary self-confidence (Montague & Garderen, 2003). Learned helplessness often manifests into a self-fulfilling prophecy, as it were, since a student who suffers from low self-conception will avoid more and more academic challenges (Covington, 1992).

Two of the most important affective factors that determine students'—both with and without MD—mathematic achievement may be math anxiety and test anxiety (Highbee & Thomas, 1999). While math anxiety is closely related to test anxiety, it is, in fact, its own entity (Bessant, 1995). Thus, many math students may suffer from both. Ashcraft & Ridley (2005) estimated the "percentages of low-, medium-, and high-math-anxious individuals at roughly 16%, 38%, and 16%, respectively" (Ashcraft, p. 320) while Burns (1998) asserted that two-thirds of American adults detest mathematics.

Helping MD students to cope with and avoid math anxiety may be particularly important, since Ashcraft & Ridley's study found that it negatively affected working memory. Given the common deficits in working memory found in students with MD, this finding is particularly applicable when deciding how to best assist math disabled students. First and foremost, instructors must avoid behaviors that engender math anxiety. Levine (1999) underlined the importance of teachers' emotional intelligence: "To prevent phobic reactions or excessive anxiety, mathematics teachers need to be compassionate, nonaccusatory, and supportive" (Levine, p. 425).

The National Council of Teachers of Mathematics (NCTM) (1989, 1995b) made several suggestions for teachers wanting to alleviate students' math anxiety. These include: accommodating for different learning styles, creating a variety of testing environments, designing positive experiences in math classes, refraining from tying self-esteem to success with math, emphasizing that everyone makes mistakes in mathematics, making math relevant, and emphasizing the importance of original, quality thinking. Hackworth (1992) suggested students evaluate their own learning, build confidence through gradual, repeated success, discuss and write about their math feelings, and learn effective study techniques.

Improving students' overall self-esteem and sense of ownership of their math learning—as well as working with them to develop relaxation techniques to use during tests—can prove effective. It is essential that teachers believe in their students' ability for success and set high standards so that students feel challenged (National Research Council Mathematics Learning Study Committee, 2006). In regard to test anxiety, instructors are to ensure to the highest possible degree that assessments are testing mathematical knowledge and not test-taking ability. These suggestions may sound obvious, but it is easy for teachers to forget the emotional and psychological components of their students' learning. In the case of students with MD, these elements are even more important to consider. Students with MD are already at a marked disadvantage and have frustrating cognitive difficulty. Thus, educational programs that include facets that can address a student's emotional health are desirable.

## Strategies, approaches, and techniques for helping students with MD

While the debate about how to define MD and its subtypes continues, a number of useful techniques for effectively teaching math to students having difficulty have been found. Although Maccini & Gagnon (2006) claimed that only extended testing time and oral presentation time have been empirically validated in math instruction for students with MD, many other strategies have been developed that help students in a more general way. Many of these are centered, unsurprisingly, on generally effective teaching methods and characteristics. It is important to keep in mind that, whether or not they have MD, students have different learning styles (auditory, visual, kinesthetic, etc.) that apply to the way in which they best understand information. Driscoll (1993) provides two categories for learning styles in mathematics: "The most frequent hypothesis advanced by theorists and investigated by researches is that there are basically two different styles of learning mathematics. One style is variously described as *analytic, verbal, and sequential*. The other has been described as *intuitive, geometric, and spatial*" (Driscoll, p. 6). Teaching to a variety of learning styles is beneficial for students with MD as well as for average achieving students. Imputing information in a variety of ways (visually, kinesthetically, aurally, etc.) reinforces students' learning. This technique is all the more important when working with MD students as they might have a deficit that makes it difficult for them to process material in a specific way (e.g., visuospatial processing deficits). Teachers can also help students with MD by modeling algorithmic procedures and good work strategies (Levine, 1999). Since students with MD often have trouble developing these approaches on their own, this technique proves especially helpful.

As demonstrated in the emotional and psychological factors section, instructors play a key role in establishing students' view towards mathematics. It should be noted that "instructor" can refer to a professor, teaching assistant, or tutor, depending on the context. High standards on the part of the instructor are crucial: "A teacher's expectations about students and the mathematics they are able to learn can powerfully influence the tasks the teacher poses for the students, the questions they are asked, they time they have to respond, and the encouragement they are given – in other words, their opportunities and motivations for learning" (National Research Council Mathematics Learning Study

Committee, p. 9). In a general mathematics class she taught to students with MD, Mary Sullivan (2005) reported that her students “praised faculty who were supportive and criticized those who wrote messages like ‘See me!’ on returned papers” (Sullivan, p. 208). Strawser and Miller (2001) argued that in order for students to achieve, an intrapersonal connection with the teacher is necessary, indicating again the important role of instructors. Nolting (2000) related that many students he has worked with have encountered professors who question their effort and motivation without understanding their disability. Students with MD already doubt their mathematical capabilities, so these types of behaviors from instructors can be particularly damaging.

Many professors may also be unaware of the challenges that students with MD face and how to best address them. In a comparison study between general education teachers and special educators, Maccini & Gagnon (2006) found that general educators were much more unlikely to use testing accommodations and other intervention strategies. However, the likelihood of using such accommodations and interventions categorically increased as teachers received more training in these techniques. In their conclusion, Maccini & Gagnon recommended that general education instructors receive more training on MD and that special educators receive additional mathematics training to assist them in helping MD students. The National Research Council Mathematics Learning Study Committee (2006) echoed this call for additional training: “Teachers’ professional development should be high quality, sustained, and systematically designed and deployed to help all students develop math proficiency” (NRCMLSC, p. 12). This is particularly true for teachers working with MD students that have more complex and specific needs.

Teaching that explicitly emphasizes conceptual understanding, problem-solving strategies and real-world relevance have proven particularly effective for mathematics students who are identified as MD, as well as mathematics students in general. Students who are successful in math are often able to see the deeper structure of mathematical problems (Hiebert & Wearne, 1986; Krutetskij, 1976). Thus, emphasizing concepts over computation is recommended. Indeed, in their study, Jitendra & Hoff (1996) found that MD students were able to improve their performance on word problems when lessons accentuated conceptual understanding and efficient strategies. Montague & Applegate (1993) indicated that math disabled students had great difficulty both selecting and applying problem-solving strategies to mathematical situations. In their recent study, Fuchs & Fuchs (2005) found that "as students master problem-solution rules, they allocate less working memory to the details of the solution and instead devote cognitive resources to identify connections between novel and familiar problems and to plan work" (Fuchs, p. 46). Since many MD students may already have working memory deficits and may additionally have trouble developing these skills, instruction that emphasizes problem-solving strategies is seemingly of great importance. Additionally, encouraging students to think about the problem-solving process through verbalization or other techniques can help them to develop better strategies and deeper understanding, as was demonstrated in the effects of embedding a study skills element into a developmental algebra course at Linn-Benton Community College in Oregon (Lewis & Clark, 2003).

Finally, connecting math to its applications outside of the classroom can motivate students to learn, which will subsequently improve their performance. Levine (1999) argues that "exporting mathematics from the classroom creates motivation to learn, and significantly reinforces concepts and operations" and that those "who perceive formal mathematics education as irrelevant are less likely to attain mastery" (Levine, p. 405). Sullivan (2005) also stresses the importance of ensuring that mathematical material is relevant as often as possible.

These recommendations are fairly general and have been shown to aid all students in improving their mathematical ability, which is even more of a reason to incorporate them into mathematics instruction whenever possible. Students with MD, however, will need more exposure to the material because they often acquire skills more slowly than their peers (Kulak, 1993). Moreover, they will probably need additional interventions that address their individual needs as their development of skills can differ greatly from what is considered to be normal.

**Recommended techniques for specific deficits associated with MD**

Arguably the greatest challenge to creating an effective policy for meeting the needs of students with MD is the heterogeneous nature of the disability. Postsecondary educators must therefore ensure that whatever programs they implement allow for individualized support. As Mazzocco & Myers (2003) articulate: "Subtype differentiation is essential for guidelines on identification and intervention strategies, and it is important to recognize that these [...] subtypes may not share one primary, core deficit" (Mazzocco & Myers, p. 224). For this reason, McGlaughlin, et al. (2005) call for interventions that focus both on specific math techniques and on other cognitive deficits in areas such as working memory and nonverbal/visual skills. Vogel, Hruby, and Adelman (1993) also note the need for individual diagnoses and a deficit-based approach to intervention.

In his book Developmental Variation and Learning Disorders, Melvin Levine (1999) proposed sets of techniques for working with MD that correspond to specific cognitive deficits. For difficulties with reading comprehension, Levine suggests that students use visual models to pair with written explanations, create an individualized mathematics glossary of terms and concepts, use math-related computer software to increase conceptual understanding, and work on developing good estimating skills so they can effectively check their work. For problems with working memory, Levine recommends that students concentrate on one task or subtask at a time, develop consistent approaches to problem solving, use self-monitoring techniques, practice extended arithmetic problems in their head to increase their working memory capacity as much as possible, and summarize complex instructions or solution processes before attempting the solution. El-Naggar (1996) suggests that instructors help students create mnemonic aids and check over written work as often as possible to ensure that when questioned about a mistake, these students remember the thought process at the time at which it was made. When helping students who have deficits in nonverbal reasoning, Levine suggests the use of manipulatives to reinforce mathematical concepts. Likewise, he notes that concrete, real-world applications of these concepts are also useful.

According to Levine, students with difficulties with math fluency should use flashcards to aid in the development of automaticity in basic arithmetic and more complex algebraic concepts, calculations, and manipulations. Mathematical computer software also helps to keep students engaged and focused, and rehearsal of common calculation methods and multi-step processes.

Nolting (2000) both suggests a set of techniques to aid students with deficits in a specific WJTCA-R, and indicates which assessment accommodations a student may need to ensure that his or her mathematics knowledge is being tested fairly. These recommendations are the most extensive and the most closely tailored to each potential deficit. Nolting stresses that in order to ascertain that the students who most need the learning skills will be successfully taught, instructors must focus on direct intervention techniques such as "orientation courses, integration of curricula that focus on affective issues into developmental reading and writing classes, special study skills courses, mentoring programs, and tutoring services with learning assistants trained to work with students with LD" (Nolting, p. 119).

For students with visual speed processing deficits, Nolting recommends note taking, student tape recorders, faculty taped lectures, advance lecture notes, key word sheets, problem sheets, video recordings, enlarged graph paper for those with difficulty writing legibly, and copies of lecture notes or lecture notes online. In terms of assessments, Nolting recommends that students with MD be allowed twice the normal amount of time for test-taking, and that the tests be 150 percent enlarged photocopies.

For visual processing deficits, students who have difficulty with visual memory and/or visual discrimination, Nolting suggests tutors to help students read textbooks, enlarged photocopies of textbooks, taking notes in different colored pens, and the use of talking calculators in addition to the aids listed for visual speed processing deficits. On tests, he indicates that these students will need twice the normal amount of time and may benefit from enlarged tests, tests that are hand-written in felt-tip pen, the capitalization of all variables (such as A's and B's as opposed to a's and b's), color-coded tests, covering tests with colored plastic overlays, test readers and/or test proofreaders, recording the test on audiocassette tape, and a private testing area. Students with auditory processing and short-term memory deficits should use school-assigned note-takers, tape recorders, physical proximity to the lecturer, videotapes and FM amplification devices, and books on tape. In "extreme" cases, Nolting advocates the use of Computer-Aided Real-time Translation (CART) devices. On tests, Nolting suggests accommodating these students with a private testing area, a test reader or tape recorded version of the test, and extended time.

For students with deficits in the cluster of long-term retrieval (working memory), Nolting advises the use of calculators (especially talking ones) as often as possible, the creation and review of concept cards, videotapes that review mathematical concepts, audiotapes of lecture or of tutoring session, and anything that may limit the requirements placed on short-term memory during problem solving. In terms of testing accommodations, he recommends the same accommodations listed for students with short-term memory deficits with the additional use of a calculator and a formula and/or fact sheet. Nolting proposes that students with deficits in long-term memory will benefit from mathematics videotapes, mathematics study skills training, note cards, calculators, detailed handouts, computer programs and tutors. During tests, he endorses open-book testing (i.e., a testing situation in which the student's lecture notes, homework assignments, previous tests, and a programmable or graphing calculator are at hand).

Students with fluid reasoning deficits will face the most challenges in learning mathematics, especially algebra, according to Nolting. They will therefore require the broadest range of accommodations out of any of the groups, especially on tests. To start, Nolting suggests note-taking, tape recorders, handouts, mathematics video tapes, concept cards, tutors and calculators, stressing that effective tutoring will make the greatest difference in such a student's learning. Mathematical information should also be presented to these students in the greatest number of ways possible (e.g., though the use of manipulatives). Nolting believes that alternative forms of evaluation may be appropriate for students with fluid reasoning deficits. However, if these disabled students are required to take a traditional test, they ought to have all the accommodations recommended for long-term memory-deficient students as well as tests divided by problem type and given over multiple days.

## Study skills

While the mathematical work that students conduct inside of the classroom is important, it is essential to remember the equal, if not greater, importance of the work done during after school hours. Students with MD will have to spend more time studying material and doing homework than their non-MD peers. Therefore, anything that can be done to ensure that these students improve their study skills by adjusting the teaching of these skills to fit individual strengths will use their study time as efficiently as possible. As shown in Nolting's and Levine's deficit-based models, some of the strategies that will most help a student with MD will be specific to whichever problem areas might be most affecting his or her performance. There are, however, many techniques that are generally beneficial for all students with MD, and many are equally useful for students without MD.

The first of these is appropriate use of a calculator when studying. Morrow (1999) indicates that calculators could be used to expand students' mathematic and scientific understanding. Students with MD may have to rely heavily on calculators when solving mathematical problems to account for working memory deficits, and using them when studying will help them prepare for this (Nolting, 2000). Students, especially those with MD, should also learn how to take effective notes (Suritsky, 1992). It may be helpful for students to take mathematical notes in a two-column format with example problems on one side and notes about the method involved in solving these problems on the other. The professors teaching the Linn-Benton Community College Developmental Algebra Course with Embedded Study Skills utilized this strategy when writing problems on the board; as a result, ninety-eight percent of students found this to be helpful (Lewis & Clark, 2003). Students with visual processing deficits can take notes on graph paper, using each column for a number, variable, or sign.

Additionally, research (Borowski & Buechel, 1983; Licht & Kistner, 1986; Schunk, 1996; Fuchs & Fuchs, 2005) suggests that students with MD need to improve their self-regulatory strategies, such as setting achievable goals. Learning how to assess one's own learning and meeting personal goals can create an important sense of empowerment and motivation in learning.

## Older learners vs. younger learners

Most of the research performed on math disability has focused on development at the elementary and pre-elementary level. Given the cumulative nature of mathematical learning, this is not surprising. In other words, because each concept in mathematics is built on a thorough understanding of the one that preceded it, researchers want to learn to detect MD as early as possible in order to lower the chance that a gap will occur between students with MD and their peers. The learning of new concepts is difficult, not to mention futile, if one's newly acquired knowledge is built on shaky foundations.

The literature often points out flaws in early mathematical development (e.g., National Research Council Mathematics Learning Study Committee, 2001), of which there are several of note, but this information is irrelevant to the community colleges that have no control over the level of mathematical competency of arriving students. Hopefully, improvements will be made to mathematics education for younger students, preparing them more effectively for the demands of postsecondary mathematics. Until then, however, community colleges must be prepared to address the mathematical problems that their students are having, especially if these include MD-related deficits.

Fortunately, much of the research that focuses on younger children has applications for students at the postsecondary level. As McGlaughlin, et al. (2005) found: "students with mathematics disabilities at the college level tend to mirror research findings for students identified with mathematics disabilities at the elementary and secondary levels" (McGlaughlin, p. 229). The areas where both of these groups showed significant weaknesses are reading comprehension, nonverbal reasoning, working memory, and math fluency.

One major difference between younger learners and older learners is that with the former, occurrence of MD will vary greatly among groups when different assessments are used. Additionally, since students develop at different rates, "over time, a given individual may or may not continue to meet a specific set of criteria for MD, even if the same measurement tools are used" (Mazzocco & Myers, p. 242). To further complicate matters, students who were diagnosed as MD when they were children may no longer fit the criterion for average intelligence when they arrive at college, due to the fact that different cutoffs for the intelligence requirement are often used at different ages (Nolting, 2000). Because development has largely slowed by the time a student reaches college age, a college student's diagnosis of MD is more likely to be permanent. Therefore, educators at the postsecondary level must impart the necessary strategies to their students in order for them to be able to learn to work around the limitations of MD.

**Programs that work for children**

If children with MD have similar difficulties to their college-age counterparts, it follows that programs that have been shown to help these children will have important practical applications at the postsecondary level. One of the most promising techniques in this area is schema-based instruction (SBI), which has most notably been studied by Fuchs & Fuchs (2005) in increasing the mathematic word problem-solving ability of children with MD. According to Parmar, Cawley, & Frazita (1996), word problem-solution is extremely challenging for children with MD because of their difficulty correctly representing these problems or identifying the relevant information within them.

In theory, as students develop normal mathematics problem-solving capabilities, they naturally begin to see the connections between problems that require the same type of solution (Chi, Feltovich, & Glaser, 1981; Gick & Holyoake, 1983; Quilici & Mayer, 1996). SBI seeks to explicitly reinforce this process. First, the student is instructed in general rules for problem solving, then he or she develops categories for problems that require the same type of solution, and finally he or she is shown the connections between seemingly novel problems and the categories previously established. Fuchs & Fuchs' research has proved this method to be very effective in improving the mathematical word problem-solving ability of children with MD.

Private tutoring has also proven effective in enriching the mathematical development of children at-risk for MD, as documented by Fuchs, et al. (2005). This study included two groups of children who were at-risk for MD and one group that was not. Over the course of one year, students in one of the groups of at-risk children were privately tutored while the other two groups in the study did not receive any private tutoring. The group that received tutoring improved significantly in mathematical achievement compared to the other at-risk group. On the other hand, the tutored group failed to improve as much as the control group of not at-risk students, suggesting that private tutoring compensated insufficiently for the effects of MD. Parker (2006) illustrated that teachers in middle school found the use of K-W-L activities (the acronym stands for "what you **k**now, what you **w**ant to know, and what you've **l**earned") a useful strategy for improving performance, as well as encouraging goal setting and self-monitoring amongst their students. Although the K-W-L model seems inappropriate for postsecondary students, this reported success indicates the important role of motivation and self-monitoring in mathematical success.

Some other effective methods for teaching math to younger students with and without MD include: having students work together in pairs or small groups (Fuchs & Fuchs, 2005), incorporating real-world scenarios into the curriculum, and explicitly connecting different topical areas (Woodward & Brown, 2006). While these methods were designed to aid younger children in learning mathematics, they present important implications for postsecondary intervention. To begin with, the effectiveness of schema-based instruction and of explicitly connecting mathematical concepts highlights the importance of encouraging conceptual thinking in combination with strategic procedural application. The results from the Fuchs, et al. study of tutoring imply that a single type of intervention may not be adequate when addressing the needs of MD students; several applications of intervention technique may be needed. Many of these approaches can, and have, been used successfully at the college level.

**Programs that work for college students**

As growing attention is paid to mathematical achievement across the educational system and as universities raise their minimum requirements for mathematics, a variety of new programs have been introduced at the postsecondary level to help students meet these rising demands. These programs have had mixed success. Initial results suggest that the level of success of these programs relies heavily on their breadth. A program seems more likely to succeed if it involves more aspects of the mathematics learning community, from professors, tutors, and counselors to modification of curriculum.

One such program is the Math Performance Success Program at De Anza College in Cupertino, CA (LaManque, 2003). To begin with, the program addresses any affective factors by ensuring that a counselor is available each class section to provide academic or individual counseling. A high-level of communication is maintained between instructors, counselors, and tutors through weekly meetings. Fifty percent of instructional time is spent working in small groups with a specifically trained tutor present and forty hours of tutoring time is offered outside of class per week. One of the great advantages of this system is that tutors and counselors are made available during class, eliminating the need for students to self-refer. A similar philosophy is shown in the program at Linn-Benton Community College that embed study skills into a Developmental Algebra Course, thereby eliminating the need for students to take an optional seminar on study skills (Lewis & Clark, 2002). As Nolting (2000) indicates, when such services are based on self-reference, students often wait until it is too late to seek help. The final results of this program were impressive: each redesigned course section managed to retain over 90 percent of its students.

Many other programs have combined various elements of the aforementioned programs with success. The vast majority of postsecondary programs aimed at improving math achievement have justly focused on the role of instructors and how time was spent during class. In her class of only three students, all of whom were MD, Sullivan (2005) “planned for them to use their strengths to compensate for their deficiencies” (Sullivan, p. 207), and ensured that her program included extensive use of calculators, often an uncommon circumstance in community college mathematics courses. Of course, this personalized approach to teaching becomes exponentially more difficult as the number of students increases. However, the success of her class indicates that playing to a student's strengths, especially when the student is MD, is important in fostering intellectual growth.

A more generalized approach is schema-based instruction, which has been shown to be effective in higher education. Quilici and Mayer (1996) show that students taking statistics in college were more successful when they grouped problems by type.

Zawaiza and Gerber (1993) found that SBI was effective in improving the mathematical problem-solving ability of college students with learning disabilities. While the results showed that these students failed to maintain their knowledge, Xin, Jitendra, & Deatline-Buchanan (2005) attribute this to the limit that the study placed on total SBI time: seventy to eighty minutes.

As many college classes are large, interventions will often rely heavily on the support of tutoring or lab work. Tutoring may also stand in for the individual attention students with MD received in lower grades. Fuchs, et al. (2005) found that the efficacy of tutoring was supported "on computation and concepts/applications" and "decreased the prevalence of math disability" (Fuchs, p. 493). As a result, the authors call for intervention "that combines classroom instruction with more intensive and individualized tutoring" (Fuchs, p. 494). Miles and Forcht (1995) also show that students with MD benefit from a tutoring technique where they simultaneously verbalized and wrote down their thought process with guidance from the tutor.

Since the learning of mathematics is often compared to the learning of a foreign language, immersion techniques have been suggested, especially for students with MD. For example, Vaidya (2004) asserts that immersion therapy is one of the most effective treatments for dyscalculia. Students in the Elementary Algebra Redesign program at Riverside Community College (Pisa, 2006) identified the weakest parts of the program as being the insufficient time and insufficient lab hours. Additionally, students in a section of the program where class time was divided equally between lecture and lab work had a higher rate of success than the students in the sections where a higher percentage of classroom was spent in lecture, thus indicating the importance of collaborative, small group work. Pisa also reported that the inclusion of this type of work was one of the greatest strengths of the program.

The benefits of both immersion and working in a small group are seen again in Sullivan's 2005 results. Her class met for twice the amount of time as traditional math classes at the same level and she indicated "substantial amount of instruction time and class size" as "major contributing factors to success" (Sullivan, p. 219). It is clear that a variety of programs can be successful in improving mathematic achievement in postsecondary students. However, those that address all the various facets involved in mathematical learning (cognitive, affective, psychological, etc.) are understandably the most effective.

## Conclusion

The complex nature of mathematical thought and therefore of mathematical disability has been a common thread, not only of this analysis, but also of all reviewed MD literature. There are a large number of component skills that make up mathematical proficiency, so educators have much to consider when deciding how best to address the needs of students with MD. It is possible that the way in which community colleges has been most clearly stated by McGlaughlin et al (2005): "Academic supports for these deficits must not only address specific mathematics difficulty areas but also the individual underlying difficulties that exacerbate poor math performance… By supporting both the math difficulty and the underlying processing deficits that exacerbate poor math performance, instructors and tutors will significantly increase students' ability to assimilate and utilize the mathematics concepts and skills needed to meet college-level mathematics requirements" (p. 231).

However, even McGlaughlin and his colleagues fail to insist upon the importance of the emotional and psychological factors of learning math and the need for institutions to help MD students to cope with the frustration and anxiety that they often feel. It is true that educators need to address these students' cognitive challenges, but they must also be provided with the tools they need to be and to feel successful in mathematics and beyond.

Mathematics is a foreign language, with its own syntax and vocabulary, and it is all the more foreign for students with MD. An immersion-based approach, therefore, seems appropriate, with the most amount of in-class time possible spent with instructors, tutors, and counselors who understand an individual students' learning disabilities and are trained to address the problems associated with them.

Community colleges, as public institutions, have an obligation to confront these issues, and while that is a great responsibility, it is also an opportunity to raise the standards of educational quality and equality.

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