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Characteristic Behaviors of Students with LD Who Have Teacher-Identified Math Weaknesses

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Abstract

Mathematics learning disabilities (LD) have gained increased attention over the last decade from both researchers and practitioners. A large percentage of students receiving learning disability services experience difficulties with mathematics, but little research has examined the specific mathematics behaviors of students with LD who have teacher-identified math weaknesses. This study examines the literature on mathematics LD and identifies specific behaviors from that body of research for the purpose of determining the extent to which those behaviors are observed in students with LD. Data are presented from observations of 391 special education professionals on 1724 students with LD, 870 of whom had identified math weaknesses and 854 of whom did not. Our results validate the existing literature and provide implications for teachers, researchers, and others interested in studying mathematics LD.

For more than 20 years, math disabilities have been recognized as a type of learning disability, as evidenced by the inclusion of mathematics in the two most influential definitions of learning disabilities (i.e., National Joint Committee on Learning Disabilities, 1990/1994; Individuals with Disabilities Education Act Amendments of 1997; see also Hallahan, Kauffman, & Lloyd, 1996; Hammill, 1990; Hammill & Bryant, 1998; Mercer, Jordan, Alstrop, & Mercer, 1996). Moreover, research efforts aimed at documenting the prevalence of mathematical disabilities (e.g., Badian, 1983; McLeod & Armstrong, 1982) have confirmed that a group of students with learning disabilities (LD) exhibit math weaknesses that warrant instructional attention. Finally, the publication of three special series (see *LD Forum, Learning Disability Quarterly, Journal of Learning Disabilities*) devoted to the dissemination of information on the nature of mathematics disabilities, assessment, curriculum, instruction, and teacher preparation has demonstrated the importance of addressing the needs of students with LD who have mathematics difficulties that may persist across the lifespan (Patton, Cronin, Bassett, & Koppel, 1997; Wagner, 1990).

Studies by Geary (1990), Ginsburg, Posner, and Russell (1981), N. C. Jordan, Levine, and Huttenlocher (1995), Rourke (1993), and others have attempted to conceptualize the cognitive and neuropsychological aspects of mathematics LD (i.e., dyscalculia) and to show how these aspects affect an individual's abilities to perform mathematical tasks. This work has been based on researchers' observations of mathematical characteristics and on empirical studies including sample groups of students with and without LD in mathematics. For instance, early work based on clinical findings led to the identification of arithmetical subtypes (Kosc, 1974) and to proposed neurological substrates (Hecaen, Angelergues, & Houillier, 1961). More recent work by Rourke (1993) identified two subtypes of arithmetical impairment (i.e., nonverbal LD and psycholinguistically based LD) based on different patterns of neuropsychological deficits and assets. Furthermore, Lerner (1993) credited Johnson (1987) and Bley and Thornton (1989) for developing a list of mathematical characteristics based on theories of psychological processing (e.g., visual and auditory processing deficits).

Other studies have provided evidence of specific behavioral characteristics in the areas of arithmetic and word problem solving. For instance, math difficulties may be evidenced in problems with (a) math fact automaticity (Garnett & Fleischner, 1983; N. C. Jordan et al., 1995); (b) arithmetic strategies (Geary, 1990; Goldman, Pellegrino, & Mertz, 1988); (c) interpretation of word problem sentence construction (Englert, Culatta, & Horn, 1987); and (d) word problem solving skills (Montague & Applegate, 1993).

An understanding of the cognitive and neuropsychological behaviors that constitute mathematical disabilities is of critical importance to professionals who are responsible for the assessment and identification of mathematical disabilities and to researchers who study the nature of LD in mathematics and who seek to validate effective interventions. Moreover, practitioners must possess a keen understanding of behaviors representative of mathematics weaknesses to help screen and identify students who may have a learning disability in mathematics and to plan their subsequent educational programs.

An emergent body of research on behaviors characteristic of students with mathematical disabilities is contributing to an understanding of the problems exhibited by students who struggle with mathematics. Given this body of research, we were interested in determining whether the math behaviors cited in the research and theoretical literature were being observed by professionals in their students with LD who have math weaknesses. That is, are math behaviors identified in the theoretical and research literature valid indicators of math weaknesses as identified by professionals who work with students with LD on a regular basis? The validity of professionals' ratings as a means of identifying student behaviors is well established as an acceptable practice in the screening and identification of LD and for the purpose of instructional decision making (Morine-Dershimer, 1978–1979). Wiederholt and Bryant (1987) noted that experienced professionals develop an internalized scope-and-sequence chart that allows them to observe students in their classrooms and make decisions about their academic abilities. Also, the accuracy of professionals' judgments has been demonstrated (Gresham, 1986; Gresham, MacMillan, & Bocian, 1997; Nelson, 1971; Shafer, 1982) and has been validated by comparing their observations with the results of standardized achievement measures (Brophy & Good, 1974; Hammill & Hresko, 1994; Keogh & Smith, 1970; McGhee, Bryant, Larsen, & Rivera, 1995; Ohlson, 1978; Wiederholt & Bryant, 1992). Thus, from a classroom standpoint based on the observations of professionals working with students with LD, we were interested in validating the math behaviors identified in the literature as problematic of students with LD who do poorly in math. We were also interested in identifying whether the mathematics behaviors reported in the literature could distinguish students with math weaknesses from students without such problems. Finally, we were interested in the predictive validity of mathematics behaviors as a classification system.

According to Ginsburg (1997), "Many children receive diagnoses of mathematics learning disability, or the related dyscalculia and acalculia. Yet, little is understood concerning these 'conditions' and how they develop" (p. 20). Thus, we sought to learn more about the "condition" of mathematics weaknesses. The purpose of this study was to validate specific behaviors associated with mathematics LD and to identify those mathematics behaviors that can be used to differentiate students with LD who experience and do not experience math weaknesses. The research questions in this study included

- Are there specific math behaviors that differentiate students with LD who have math weaknesses from students with LD who do not have math weaknesses?
- Which behaviors are most predictive of math weakness versus math nonweakness in group assignments for students with LD?

Method

A rating scale was created that examined identified behaviors in mathematics LD. The scale was sent to professionals who worked with students with LD; they were asked to complete the rating scale on students in their caseload.

Rater Characteristics

Professionals who worked with students with LD were asked to rate their students' math behaviors. Raters were identified in the following way: A listing containing names and addresses of 15,000 randomly selected teachers, clinicians, and therapists who worked primarily in the area of LD was purchased from a commercial mailing list company. The company's listing included more than 3.4 million educators, of whom 56,258 were professionals who worked with students with LD; this is the group from which the random sample was drawn. The selected professionals were sent letters inviting them to participate in our study. In all, 391 professionals (raters) from 42 states and the District of Columbia agreed to participate. The characteristics of the raters are presented in Table 1.

Student Characteristics

Ratings were completed by professionals on 1,724 students who ranged in age from 8 years 0 months to 18 years 11 months (M = 11 years 10 months), were officially diagnosed by their school district as having learning disabilities (LD), and were receiving special education services in Grades 1 through 12. The demographic characteristics of the student sample (e.g., gender, race, ethnicity, placement) are listed in Table 2. Using data from Hammill and Bryant (1998), we found that the sample was generally representative of the population of students with LD as depicted by statistics provided by the federal government.

Raters were asked to identify whether the rated student had weaknesses in any of the six areas (i.e., listening, speaking, reading, writing, mathematics, reasoning) identified in the National Joint Committee on Learning Disabilities (1990/1994) definition of LD. Of the 1,724 students with LD in the sample, 870 (50%) were identified by the professionals as having weaknesses in mathematics; 854 students did not have math weaknesses. The

TABLE 1
Demographic Characteristics of the Raters

Variables	N
Age	
18–34 years old	89
35–44 years old	139
45–54 years old	127
55 years and older	36
Experience	
0–5 years	61
6–15 years	148
16+ years	182
Position	
General education teacher	8
Special education teacher	361
Other	22
Race	
White	380
Black	8
Other	3
Gender	
Men	39
Women	352
Ethnicity	
European American	359
African American	8
Hispanic American	3
Asian American	10
Other	11
Education	
Bachelor's degree	111
Master's degree	268
EdS	8
Doctorate	4
Setting	
Public school	329
Private school	54
Other	8

math performance of the students in this group as identified by the raters formed the basis of our study. Interestingly, we were unable to locate national prevalence figures on mathematics weaknesses in the LD population. We suspect that this study might be one of the first estimates of the prevalence of mathematics weaknesses in LD.

Instrument

The mathematics section of the rating scale was used by professionals to rate their students. The final version of the rating scale was composed of 33 items that described specific behaviors associated with LD in mathematics. Several procedures were used to develop and validate the scale items including a review of the literature, a review by a panel of experts, and empirical item analyses techniques.

TABLE 2
Demographic Characteristics of the Student Sample

Variables	N
Gender	
Boys	1213
Girls	511
Ethnicity	
European American	1247
African American	243
Hispanic	116
Other	118
Age	
8	145
9	239
10	242
11	215
12	154
13	165
14	112
15	127
16	140
17	148
18	37
Race	
White	1373
Black	244
Other	107
Placement location	
General education	647
Resource room	602
Self-contained class	202
Other	273

A corpus of research and theoretical literature dealing with characteristics of specific LD in mathematics was reviewed. Research articles, textbooks, diagnostic tests and rating inventories, and theoretical pieces from the fields of LD and neuropsychology composed this body of literature. The purpose was to identify specific, observable behaviors exhibited by students with math LD. A total of 32 such behaviors or items were identified; these items served as the first version of the rating scale.

Next, we invited 75 experts in LD to examine our rating scale to identify the extent to which the behaviors we had identified in the literature were indeed reflective of math LD. These experts were people who had served on executive committees of LD organizations, were leading researchers in LD, or were authors of leading texts on LD. Thirty-six of the 75 experts agreed to participate in the validation study of our rating scale. Of the 36 expert panel members, 33 held doctorates, 25 were college professors, and 8 were primarily professionals working in private practice as consultants or diagnosticians. Two of the panel members were parents of individuals with LD and were also officials in national LD organizations.

Panel members were asked to identify the degree (*minimal*, *somewhat*, or *considerable*) to which each of the items on the rating scale was indicative of a learning disability in mathematics. The panel members were also requested to provide any additional behaviors that might not have been on the scale but that, in their opinion, were associated with math LD. The panel members identified five additional behaviors, three of which were listed by more than one panel member. These three behaviors were added to the scale. Two of the original items were deleted because they were viewed as minimally indicative of math LD by at least two thirds of the panel, which brought the item total to 33. This revision became the final version of the scale used in this study. The items, their citations, and expert panel ratings are found in Table 3.

Once data were gathered on the scale using the procedures described in the next section, empirical evidence was obtained for the scale's reliability and the validity of its items. Internal consistency reliability coefficients for the math weakness and math nonweakness groups were .97 and .96, respectively, and median discriminating powers for each item within each group met or exceeded .49 (see Table 3), demonstrating each item's validity (Guilford & Fruchter, 1978). Fur-

TABLE 3
Content Validity of the Math Behaviors Used in the Study

Mathematics behavior (Citations)	Panel ratings			Item-total coefficients	
	M%	S%	C%	r_{mw}	r_{mn}
Does not recognize operator signs (e.g., +, –; Gordon, 1992; Strang & Rourke, 1985; Sutaria, 1985)	7	54	39	.59	.58
Fails to read accurately the correct value of multidigit numbers because of their order and spacing (Blalock, 1987; Cohn, 1968)	4	32	64	.75	.75
Fails to carry (i.e., regroup) numbers when appropriate (Cohn, 1968)	7	33	60	.76	.79
Orders and spaces numbers inaccurately in multiplication and division (Cohn, 1968)	4	32	64	.73	.77
Misplaces digits in multidigit numbers (Bley & Thornton, 1995; Hartje, 1987; D. R. Jordan, 1996)	4	19	73	.79	.80
Misaligns horizontal numbers in large numbers (Bley & Thornton, 1995; Coon, Waguespack, & Polk, 1994; Denckla, 1978; Rourke, 1982; Sutaria, 1985)	4	33	63	.80	.79
Omits digits on left or right side of a number (Hartje, 1987)	4	35	61	.68	.71
Starts the calculation from the wrong place (Hartje, 1987)	8	42	50	.71	.72
Makes "borrowing" (i.e., regrouping, renaming) errors (Bley & Thornton, 1995; Hartje, 1987; D. R. Jordan, 1996)	4	27	69	.71	.81
Skips rows or columns when calculating (i.e., loses his or her place; Hartje, 1987)	7	29	64	.76	.80
Disregards decimals (Hartje, 1987)	7	37	56	.66	.74
Misaligns vertical numbers in columns (Bley & Thornton, 1995; Coon et al., 1994; Denckla, 1978; Rourke, 1982; Sutaria, 1985)	4	37	59	.79	.79
Misreads computational signs (e.g., reads + as –; Cohn, 1968)	8	38	54	.72	.73
Reverses numbers in problems (Bley & Thornton, 1995; Cavey, 1993; Greene, n.d.; Strang & Rourke, 1985; Sutaria, 1985)	0	39	61	.71	.73
Reaches "unreasonable" answers (Strang & Rourke, 1985)	3	19	78	.67	.76
Does not remember number words or digits (McCloskey, Sokol, Goodman-Schulman, & Caramazza, 1990; Rourke, 1991)	0	52	48	.68	.74
Writes numbers illegibly (Pennington, 1991; Rourke, 1982)	21	43	36	.51	.53
Misspells number words (writes 13 as *threeteen,* 20 as *twoty*; McCloskey et al., 1990)	24	44	32	.52	.50
Cannot recall number facts automatically (i.e., unable to perform simple calculations; Badian, 1983; Garnett & Fleischner, 1983; Greene, n.d.; Johnson, 1995; Johnson & Myklebust, 1967; Kass & Maddux, 1993; Luria, 1966)	0	30	70	.63	.70
Counts on fingers (Greene, n.d.; Johnson, 1995; D. R. Jordan, 1996; Luria, 1966)	15	54	31	.57	.63
Does not follow spatial commands or directions (e.g., "place the triangle above the cross"; Bley & Thornton, 1995; Luria, 1966)	4	33	63	.63	.68
Jumps impulsively into arithmetic operations (Luria, 1966)	11	33	56	.51	.62
Fails to verify answers and settles for first answer (Luria, 1966; National Joint Committee on Learning Disabilities, 1996)	7	41	52	.54	.66
Exhibits left-right disorientation of numbers (Greene, n.d.; Mazzoni, 1990; PeBenito, Fisch, & Fisch, 1988; Sutaria, 1985)	4	30	66	.67	.73
Cannot copy numbers accurately (Sutaria, 1985)	12	38	50	.70	.69
Has difficulty learning to tell time (Bley & Thornton, 1995)	8	42	50	.62	.67
Calculates poorly when the order of digit presentation is altered (Warrington, 1982)	0	37	63	.76	.83
Takes a long time to complete calculations (D. R. Jordan, 1996; Warrington, 1982)	4	36	60	.61	.72
Makes errors when reading arabic numbers aloud (McCloskey & Caramazza, 1987)	15	38	47	.65	.71

(table continues)

(Table 3 continued)

Mathematics behavior (Citations)	Panel ratings			Item-total coefficients	
	M%	S%	C%	r_{mw}	r_{mn}
Experiences difficulties in the spatial arrangement of numbers (Gaddes, 1985; Hecaen, Angelergues, & Houillier, 1961)	0	46	54	.76	.80
Has difficulty with multi-step problems (Bley & Thornton, 1995; panel addition)	NA	NA	NA	.57	.74
Has difficulty with the language of math (Johnson & Myklebust, 1967; panel addition)	NA	NA	NA	.58	.66
Has difficulty with word problems (Bley & Thornton, 1995; Johnson & Blalock, 1982; Johnson & Myklebust, 1967; D. R. Jordan, 1996; panel addition)	NA	NA	NA	.49	.62

Note. M% = Percentage of panel members rating the behaviors as minimally related to math LD. S% = Percentage of panel members rating the behaviors as somewhat related to math LD. C% = Percentage of panel members rating the behaviors as considerably related to math LD. r_{mw} = Math weakness. r_{mn} = Math nonweakness. NA = not applicable.

ther evidence of the scale's reliability is found in two separate studies reported by Hammill and Bryant (1998). These researchers conducted test–retest and interrater reliability studies using 15 of the 32 original scale items. Because this shortened version of the scale correlates with the longer scale at .97, the coefficients of .88 for test–retest and .91 for interrater reliability provide further evidence of the scale's reliability.

To further examine the validity of the scale's items, we conducted a maximum likelihood factor analysis on the items for each group (i.e., math weakness and math nonweakness). For each group, all items loaded on a single factor, demonstrating the presence of an overall math abilities factor represented by the scale.

Prior to examining the research questions, we ran a correlational analysis to determine the relationship between item performance and participant age. In addition to providing information about the developmental nature of math LD (i.e., how math behaviors change over time), the resulting coefficients told us whether we could collapse our data or whether we needed to run our analyses at different ages separately to account for the influences of age. The resulting coefficients ranged from .06 through .35 (*Mdn* = .19; all coefficients significant at $p < .01$), depicting a negligible correlation between age and performance and providing support for collapsing the data into one data set.

Procedure

Once professionals agreed to participate in the study, they were asked to randomly select up to five of their students with LD. The raters were asked to read each math item on the rating scale and, using a Likert-type response format, identify and rate the frequency with which each target student exhibited the behavior (1, 2, 3 = *frequently;* 4, 5, 6 = *sometimes;* 7, 8, 9 = *rarely*). Raters were asked to *not* consider the student's behavior in relation to the behaviors of other students of his or her own age; instead, they were asked to simply rate the frequency of the behaviors. The scale was of the machine-scorable type; raters filled in the bubble of the number that reflected their response. When the ratings were completed, scales were placed in a postage-paid envelope, returned to the researchers, and scored using an electronic scanner.

Results

Mathematics Behaviors of Students with LD

In the student characteristics section, we discussed how our sample was divided into two groups; those with math weaknesses (MW), $n = 870$; and those without math weaknesses (MN), $n = 854$. Means and standard deviations for each math behavior for both groups (MW, MN) are reported in Table 4. Differences between means were analyzed by use of a *t* test for each of the math behaviors; these data, along with mean differences, are reported in Table 4. Behaviors are listed in Table 4 according to their frequency of occurrence for the math weakness group. Statistically significant differences ($p < .05$) were found between groups for all of the math behaviors, which indicates that the behaviors cited in the research and theoretical literature are indeed observed by professionals to a greater extent in students with math weaknesses than in students who do not do poorly in math. To correct for possible type I error, the Bonferroni adjustment was applied, and all differences met the criterion of $p < .0015$.

Behaviors Predictive of Group Assignment

A forward inclusion stepwise regression procedure was used to determine which behaviors best predict the classification of mathematics weakness for students with LD. Each behavior was entered into the regression equation according to the greatest amount of variance unexplained by the behaviors already examined in the equation. The process was completed when the combination of variables no longer contributed significantly to the examination (criteria of probability to enter was set at $p \leq .05$; the criteria of probability to remove was set at $p \geq .05$). As can be seen in Table 5, nine behaviors con-

TABLE 4
Behavior Comparisons Across Groups

Behavior	MW *M*	MW *SD*	MN *M*	MN *SD*	*M* diff	*df*	t_1
Has difficulty with word problems	2.3	1.6	4.1	2.5	1.7	1, 1266	17.0
Has difficulty with multi-step problems	2.6	1.8	5.0	2.5	2.4	1, 1346	22.6
Has difficulty with the language of math	3.1	2.0	5.2	2.4	1.9	1, 1448	18.8
Fails to verify answers and settles for first answer	3.2	2.1	5.3	2.6	2.1	1, 1472	17.9
Cannot recall number facts automatically (i.e., unable to perform simple calculations)	3.9	2.4	6.3	2.3	2.4	1, 1583	20.0
Takes a long time to complete calculations	4.0	2.3	6.3	2.3	2.3	1, 1575	19.4
Makes "borrowing" (i.e., regrouping, renaming) errors	4.1	2.2	6.7	2.1	2.6	1, 1574	22.8
Counts on fingers	4.2	2.6	6.4	2.4	2.2	1, 1584	17.4
Reaches "unreasonable" answers	4.3	2.1	6.5	2.0	2.2	1, 1576	21.3
Misspells number words (writes 13 as *threeteen,* 20 as *twoty*)	4.5	2.7	5.3	2.8	0.8	1, 1531	6.1
Calculates poorly when the order of digit presentation is altered	4.6	2.3	6.8	2.0	2.2	1, 1579	20.4
Orders and spaces numbers inaccurately in multiplication and division	4.6	2.4	6.8	2.1	2.2	1, 1556	19.8
Misaligns vertical numbers in columns	4.6	2.2	6.5	2.1	1.9	1, 1578	17.5
Disregards decimals	4.7	2.4	6.8	2.1	2.1	1, 1548	19.3
Fails to carry (i.e., regroup) numbers when appropriate	4.7	2.3	6.9	2.0	2.2	1, 1579	19.5
Fails to read accurately the correct value of multidigit numbers because of their order and spacing	4.8	2.4	7.0	2.0	2.2	1, 1579	19.5
Jumps impulsively into arithmetic operations	4.9	2.5	6.5	2.2	1.6	1, 1583	13.6
Misplaces digits in multidigit numbers	4.9	2.4	6.9	2.1	2.0	1, 1572	18.4
Misaligns horizontal numbers in large numbers	4.9	2.5	6.9	2.1	2.0	1, 1568	17.4
Skips rows or columns when calculating (i.e., loses his or her place)	5.0	2.4	6.9	2.0	1.9	1, 1575	17.2
Makes errors when reading arabic numbers aloud	5.1	2.4	6.7	2.2	1.6	1, 1560	14.2
Experiences difficulties in the spatial arrangement of numbers	5.2	2.3	6.9	2.0	1.7	1, 1571	16.0
Does not follow spatial commands or directions (e.g., "place the triangle above the cross")	5.4	2.3	6.9	2.0	1.5	1, 1574	14.0
Misreads computational signs (e.g., reads + as –)	5.4	2.3	7.2	1.9	1.8	1, 1552	16.3
Reverses numbers in problems	5.4	2.4	6.9	2.0	1.5	1, 1571	13.7
Has difficulty learning to tell time	5.6	2.6	7.2	2.1	1.6	1, 1550	13.5
Does not remember number words or digits	5.7	2.4	7.1	2.0	1.4	1, 1557	12.4
Writes numbers illegibly	5.8	2.5	6.8	2.3	1.0	1, 1583	7.4
Starts the calculation from the wrong place	5.9	2.4	7.6	1.6	1.7	1, 1461	16.8
Cannot copy numbers accurately	6.0	2.3	7.2	1.9	1.2	1, 1568	11.0
Exhibits left-right disorientation of numbers	6.1	2.4	7.5	1.7	1.4	1, 1508	13.0
Omits digits on left or right side of a number	6.2	2.4	7.7	1.6	1.5	1, 1433	14.2
Does not recognize operator signs (e.g., +, –)	6.8	2.3	7.8	1.6	1.0	1, 1486	10.8

Note. Behaviors are ranked in order of frequency of occurrence for the MW group. MW = Math weakness. MN = Math nonweakness. *M* diff = mean difference between groups. t_1 = *t* value ($p < .05$); all values met Bonferroni adjustment criterion ($p < .0015$)

TABLE 5
Summary of Stepwise Regression Procedure

Step	Variable entered	Multiple *r*	r^2	Increase in r^2
1	Has difficulty with multi-step problems	.508	.258	.258
2	Makes "borrowing" (i.e., regrouping, renaming) errors	.555	.308	.050
3	Cannot recall number facts automatically (i.e., unable to perform simple calculations)	.564	.318	.010
4	Misspells number words (writes 13 as *threeteen*, 20 as *twoty*)	.575	.330	.012
5	Reaches "unreasonable" answers	.581	.337	.007
6	Calculates poorly when the order of digit presentation is altered	.584	.341	.004
7	Cannot copy numbers accurately	.589	.346	.005
8	Orders and spaces numbers inaccurately in multiplication and division	.592	.350	.004
9	Does not remember number words or digits	.595	.354	.004

tributed significantly to group placement, with the first two behaviors accounting for just less than 31% of the total variance. The addition of the remaining seven behaviors accounted for an increase of slightly less than 5% of the total variance explained by the regression procedure.

Discussion

The purposes of this study were to validate those mathematics behaviors that can be used to discriminate students with LD who have math weaknesses from students without math weaknesses and to identify math behaviors predictive of MW versus MN group assignment for students with LD. Findings from the *t* test analyses showed statistically significant differences between the MW and MN groups, which can be used to validate the existence of a group of behaviors identified in the literature that constitute mathematics disabilities and that can be used to identify students as having math weaknesses in need of remediation. Significantly, the math behaviors identified by researchers, often in controlled settings, are indeed validated (i.e., observed) by professionals who instruct students with LD who possess math weaknesses. These findings have several implications.

First, the results have implications for the identification by classroom teachers of students with potential LD in mathematics. General education teachers tend to be the first to refer a student for special education evaluation—a decision which is usually based on their analysis of the student's classroom achievement and behavior. Armed with empirically validated behaviors indicative of possible math disabilities (i.e., "red flags"), teachers would be in a better position to make informed decisions about children who struggle with learning mathematics and whose math weaknesses may have gone undetected.

Second, our findings have instructional implications for children who do poorly in math and for their teachers. The performance behaviors validated in this study can provide teachers with insight into specific math behaviors that must be scrutinized carefully in their students for instructional decision-making purposes. Knowing that these math behaviors may occur in some children in their classrooms, teachers can take a proactive approach to instructional planning and implementation and be prepared with techniques to remediate troublesome areas (e.g., graph paper to prevent alignment problems).

Third, the results from this study have implications for preservice teacher preparation programs. Parmar and Cawley (1997) called for teacher education programs to provide preservice teachers with more information about the research in mathematics and the characteristics of the students. Preservice teachers need to know characteristic math behaviors that are exhibited by students with LD who have math weaknesses. Equipped with such knowledge, teachers will be better prepared to identify students at risk for math LD and to select appropriate remedial and instructional techniques that can be attempted before special education referrals are initiated.

Fourth, examination of the math behaviors exhibited by students who do poorly in math suggests that sound research studies should be undertaken to identify effective remedial approaches for the various identified weaknesses (e.g., place value, time, number recognition, regrouping). Yet according to a recent review of mathematics intervention research, few studies have occurred since 1975 in the areas of time, money, and place value (Bryant & Dix, 1998) and math word problems (Rivera, Smith, Goodwin, & Bryant, 1998)—behaviors which were cited as problematic for students with math weaknesses.

Fifth, our findings have implications for those who design and implement technology adaptations for students with academic problems. As technology offers unique opportunities for adaptations that can help students compensate for academic weaknesses exhibited in the classroom (Bryant & Bryant, 1998; Raskind & Higgins, 1998), further development of hardware and software solutions focused on the math behaviors cited here can provide valuable instructional alternatives for students with math weaknesses.

On closer examination of the ranked mathematical behaviors identified for the MW group, the top-ranked behaviors (i.e., behaviors that had mean scores represented as *frequent* on a scale of 1 to 3) warrant discussion. Not surprising, the average rating ($M = 2.3$) for word problems indicated that this skill is most problematic for students with LD who have math weaknesses. This finding further validates results reported in the literature that word problem solving is an area of great weakness for students with mathematical disabilities across the elementary (Englert et al., 1987; Parmar, Cawley, & Frazita, 1996), secondary, (Montague & Applegate, 1993; Parmar et al., 1996), and postsecondary (Zentall & Ferkis, 1993) grade levels. Further analyses by teachers are required to discern the behaviors (e.g., reading, syntax, computation, multi-step, type of word problem structure) that interfere with student ability to solve word problems. Interesting and not surprising, word problem solving difficulties were noted among the math nonweakness group as well, which is reflected in national assessment data and calls for educational reform (McKnight et al., 1987; National Council of Teachers of Mathematics, 1989). Thus, word problem solving remains a challenging task that demands instructional attention in our schools.

The second-ranked math behavior, "has difficulty with multi-step problems," has application to a variety of math skills and warrants careful instructional consideration. We interpret the ranking of this math behavior as indicative of the need for teachers to task-analyze skills carefully and to provide students with strategies for remembering and executing multiple steps to solve mathematical problems. Whole number computation, fractions, word problem solving, and algebra—to name a few—require students to engage in multiple steps as part of the solution-finding process. It appears that students may require sequenced, explicit, systematic teaching with practice and corrective feedback (Jones, Wilson, & Bhojwani, 1997) coupled with activities that promote meaningful understanding of the steps inherent in solving mathematical problems (Thornton, Langrall, & Jones, 1997).

The third-ranked behavior, "has difficulty with the language of math," can be interpreted in light of the work of Wiig and Semel (1984). Mathematics is *conceptually dense*; that is, students must understand the meaning of mathematical symbols and words because, unlike reading, contextual clues are limited or nonexistent. Instructional implications suggest that vocabulary (e.g., numerator, difference, sum, minuend) and abstract symbols (e.g., <, >, +) specific to each math lesson should be identified and taught according to what we know about effective instructional routines (e.g., explicit instruction, examples, and guided practice; Rivera & Smith, 1997).

Finally, the high ranking of "fails to verify answers and settles for first answer" is indicative of a general trend among students with math weaknesses not to check their work for mistakes. Intuitively, this result is not surprising for students who find solving mathematics problems an arduous task. One can surmise that students who struggle with mathematics might be reluctant to recheck their work once the final solution is reached.

The results of the regression study also yield information of interest. Although the regression model identified nine variables (see Table 5), only two variables merit discussion because they accounted for the most variance. The first variable, "has difficulty with multi-step problems," is the single most important behavior for predicting math weaknesses, accounting for more than one fourth of the variance. When coupled with the second variable, "makes 'borrowing' (i.e., regrouping, renaming) errors," just under 31% of the variance is accounted for. Clearly, students are in need of instruction that helps them work through the multiple steps inherent in many mathematical equations. Simple modeling and practice alone may be insufficient; students may require specific task-analyzed instruction and cognitive strategies to help them work through and remember solution steps. Errors in renaming are often indicative of a conceptual misunderstanding of place value and its application to subtraction problems. Recognizing that larger numerals in the subtrahend cannot be subtracted from smaller numerals in the minuend, and knowing how to use place value logic to remedy the situation, are complex tasks that are difficult for some students to grasp.

A second implication from our regression study relates to one made earlier based on our mean differences study. For identification purposes, teachers should recognize that the presence in their students of the two behaviors cited in the regression study (i.e., "has difficulty with multi-step problems" and "makes 'borrowing' [i.e., regrouping, renaming] errors") indicates potentially serious difficulties in these students. Although we would not suggest that the presence of these two behaviors alone signifies the presence of a mathematics learning disability, our data do suggest that the "red flags" associated with all the behaviors identified earlier become "crimson flags"when these two particular behaviors are also observed. If the behaviors persist despite intensive, individualized remedial efforts in the general education classroom or with remedial specialists, *and* if other behaviors cited earlier are present, it is quite possible that the student has a mathematics learning disability and should be evaluated for that possibility.

Conclusions

It is well documented that students with math LD leave high school with demonstrably lower levels of mathematics achievement than their peer group (Wagner, 1990). As shown in our study, given the poor performance of students with LD who have math weaknesses compared to their peer group, there is a sense of urgency that teachers provide intensive instruction in mathematics. The literature-based mathematical behaviors validated in this study can be used to identify students with mathematics weaknesses who may have potential mathematics LD. Moreover, the specific mathematical behaviors examined in this study provide instructional objectives for classroom teachers and curricular content for preservice teacher preparation introductory courses on LD. Finally, researchers can use the information presented in this study to create and validate instructional programs to assist teachers in their remedial and compensatory efforts.

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