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FEEDBACK FACILITATES THE ACQUISITION AND RETENTION OF NUMERICAL FACT SERIES BY ELEMENTARY SCHOOL STUDENTS WITH MATHEMATICS LEARNING DISABILITIES

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The effects of feedback to assist elementary school students classified as either normally achieving (NA) or with a mathematics learning disability (MLD) in acquiring the fact series of 0 to 9 for the operations of addition, subtraction, multiplication, and division were examined in Study 1. The acquisition of each fact series was facilitated by immediate, but not by delayed feedback, the latter of which was no more effective than control procedures. The students with math disabilities were tested with either delayed feedback or a Scantron form in Study 1, then participated in Study 2, in which they were provided with feedback from either an educator or the Immediate Feedback Assessment Technique (IF AT). The beneficial effects of immediate feedback reported in Study 1 were replicated and extended during maintenance which continued for as many as 25 sessions. The effects of auditory feedback provided by an educator and visual feedback provided by the IF AT were compared with the effects of combined auditory and visual feedback provided by the Write-Say method in Study 3. The integrated presentation of auditory and visual feedback was no more effective than the use of either modality, separately. The comparable effectiveness of feedback by an educator and by the IF AT, and the nonsynergistic effects of combining auditory with visual feedback, suggests that a response medium such as the IF AT has considerable adjunctive potential to assist in the instruction of elementary school students with special learning needs.

There has been tremendous progress in the definition and measurement of learning disabilities during the past 20 years, especially within the domain of reading disabilities for which core deficits and putative genetic etiologies have been identified (e.g., Morris et al., 1998). Similar gains have yet to be realized for the domain of math disabilities (Greiffenstein & Baker, 2002; Mazzocco, 2001), the prevalence of which in some reports

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meets or exceeds estimates reported for reading disabilities (e.g., Badian, Hatton, & Skinner, 1983). One of the most commonly reported sources of difficulty for students with math disabilities is the poor fit between the design of instructional materials and student learning characteristics, such as memory skills and strategy acquisition (e.g., Cawley, Parmar, Yan, & Miller, 1996, 1998).

The deficits in core knowledge and computational skills are compounded by the repeated demonstration that children with math disabilities, during longitudinal assessments, appear to alter neither their mixture of problem-solving strategies nor their rate of executing counting and memory retrieval strategies (Geary, Brown, & Samaranayake, 1991). The robust differences in strategies between normally achieving (NA) students and those with math learning disabilities (MLD) suggests that the involvement of long-term memory structures (e.g., Goldman, Mertz, & Pellegrino, 1989) within which basic arithmetic facts can be stored, organized, and retrieved, appear to be either incomplete or dysfunctional, and these irregularities may play a central role in math disabilities (Geary & Brown, 1991; Jordan & Hanich, 2000). The lack of intact long-term memory stores, and the concurrent deficits in fact-retrieval, have been demonstrated to persist throughout the elementary school years (Ostad, 1999), resulting in computational deficits that remain remarkably static (Cawley et al., 1998). The memorial consequences of these deficits have prompted educators to develop compensatory techniques that help students with math disabilities to overcome their difficulties with the acquisition and retrieval of core mathematical facts and computational skills, many of which were borrowed from studies of children with reading disabilities.

For example, a review of the outcomes of studies on the effects of the self-correction of errors during oral reading upon the recognition of words and the comprehension of text materials indicates that error correction is most likely to result and to be maintained when errors are corrected immediately and students are repeatedly exposed to the correct answer (Heubusch & Lloyd, 1998). The correction of errors and the repetition of and thus exposure to the correct answer defines the Write-Say method. The Write-Say method is a technique that has been used for children with learning disabilities to enhance acquisition of vocabulary (Perkins, 1988), spelling accuracy (Kearney & Drabman, 1993), textual understanding (Brown, 1982), metaphor comprehension (Baechle & Lian, 1990), mathematical operations (Lombardo & Drabman, 1985), and to decrease oral reading errors (Pany & McCoy, 1988). The central factors cited in the studies described above are the provision of immediate and corrective feedback and the use of this information by the learner to monitor performance and degree of mastery.

The literature that supports the enhancement of acquisition and retention of academic materials following the provision of performance feedback to children with learning disabilities (Caldwell, Wolery, Werts, & Caldwell, 1996), to preschool and elementary school children with general delays (Epstein, Brosvic, Dihoff, Lazarus, Costner, 2003), and to children classified with mild mental retardation (Bennett & Cavanaugh, 1998; Dihoff, Brosvic, Epstein, & Cook, 2004) continues be fractionated into camps that promote the use of computer-assisted instruction rather than paper-and-pencil techniques, the provision of immediate rather than delayed feedback, and the use of peer groups within which answers are

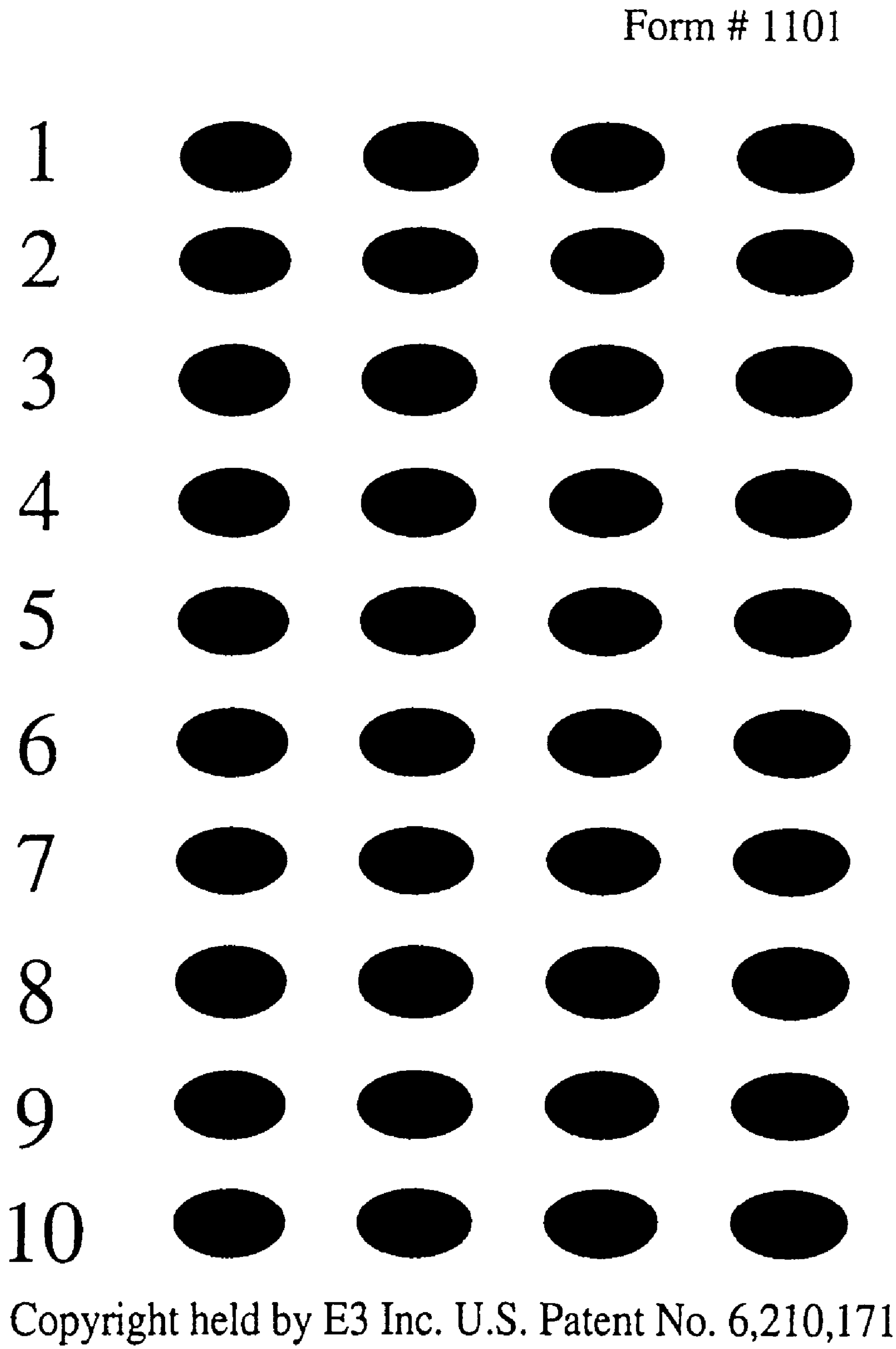

Figure 1. Sample portion of the Immediate Feedback Assessment Technique (IF AT) form. Patent is held by E3 Corporation.

collectively established and refined rather than the individual assessment of the learner (Robinson, DePascale, & Roberts, 1989). In our experience, it is difficult to provide affirming and corrective feedback on objective classroom examinations in the absence of computers, and there are few institutions with sufficient resources to deliver computer-based testing to more than a small portion of the average elementary school class. Until recently, the simple and practical means by which immediate feedback might be provided in the classroom was not available. In recent studies conducted in our laboratory and classrooms, we have developed and validated an assessment tool through which individualized performace feedback is coupled with the opportunity to answer until correct using simple paper and pencil media (e.g., Dihoff, Brosvic, & Epstein, 2003). This tool (see Figure 1) is the Immediate Feedback Assessment Techinque, or IF AT, which embodies the theoretical and practical foundations of the early teaching-testing machines described by Pressey (1950) and Skinner (1968), transforming the passive receiver of information into the active demonstrator of skills and knowledge.

The effectiveness of the IF AT has been demonstrated in our classrooms and laboratories, with the provision of corrective information increasing the acquisition of course materials and decreasing the likelihood of incorrect perseverative responding (e.g., Dihoff et al., 2003). Students without known learning difficulties (elementary school students through college students) report that using the IF AT increases interest and involvement in the assessment process, and provides the opportunity to exit each test item with knowledge rather than doubt. Students with learning difficulties report that using the IF AT increases the acquisition of basic academic materials, enhances rote memorization once a concept and the function of that concept are grasped (e.g., learning arithmetic fact series in discrete units), and that the answer-until-correct feature treats each test item as a discrete unit that can be resolved before transitioning to the next test item without engendering frustration. The most common benefits of the IF AT that have been reported by the educators of special need students in their classrooms and resource rooms are the provision of affirming and corrective feedback, and that the answer-until-correct procedure prompts students to continue to respond until the correct solution is attained. Thus, the IF AT can be highly effective for assisting learners during rote memorization drills, such as those used to acquire mathematical fact series, but it should not be expected to be as effective for teaching concepts and their applications and functions, since the concept and function of an arithmetic operation, in keeping with NCTM 2000 principles and standards (National Council of Teachers of Mathematics, 2000), must be presented by an educator. However, the encouragement of active learning, the provision of immediate feedback, and the use of an answer-until-correct procedure that maximizes time on task, are cardinal principles of pedagogy that can be easily delegated to the IF AT.

The present studies were undertaken to examine how different methods of delivering feedback affect the acquisition of fact series by elementary school students classified with math disabilities. A review of each student's mathematics examinations indicated high rates of inaccurate perseverative responding, while observation of their learning environments indicated that most students required high rates of verbal prompting to maintain responding. These learning difficulties and classroom behaviors suggested the opportunity to evaluate the adjunctive potential of the IF AT.

Study 1: Effects of Immediate and Delayed Feedback on the Acquisition and Maintenance of Arithmetic Fact Series

Method

Participants. Participants included 26 male and 14 female students enrolled in 3rd grade classes at an urban elementary school and classified with a learning disability in mathematics (MLD). A second sample of 26 male and 14 female students enrolled in 3rd grade classes at the same urban elementary school and classified as normally achieving in mathematics (NA) was included for control purposes. Participants were drawn from a larger sample from which children diagnosed with either attention-deficit/hyperactivity disorder or reading difficulties were not selected. No participant in either group had prior experience with educational interventions that included either immediate feedback or the Write-Say method. The representative MLD and NA participant was an African-American male from a birth family of low SES standing (United States Department of Health and Human Services, 2002) who had participated in preschool programs (e.g., Head Start); the MLD participant had an academic record of satisfactory performance in all content areas except mathematics. The parents of the MLD children reported concern over their children's performance in mathematics and the parents of both the MLD and the NA children expressed concern over the quality of their children's instruction. Descriptive statistics for performance on the WISC-III and the WRAT-R are presented in Table 1. Selection criteria for participants required that WISC-III scores and WRAT-R reading and spelling standard scores fall within normal limits, so that math performance was the main discriminator between the two samples. The MLD and NA groups differed on neither WISC-III full-scale and subscale scores nor on

Table 1

Means and Standard Deviations for WISC-III and WRAT-R Standard Scores in Study 1

	Math Difficulties		Normally Achieving	
	M	*SD*	*M*	*SD*
WISC - III				
FSIQ	92.85	12.55	93.02	10.82
Verbal	92.67	13.45	91.92	15.34
Performance	91.56	16.02	90.15	13.78
Reading SS	90.58	12.82	91.25	14.25
Spelling SS	89.81	14.78	90.72	12.57
Arithmetic SS	61.89	6.81	87.63	15.78

Note. WRAT-R = Wide Range Achievement Test - Revised; SS = Standard Score

WRAT-R standard scores for reading and spelling, all $F < 1$, all $p > .5$; MLD participants demonstrated significantly lower WRAT-R arithmetic standard scores than did NA participants, $F = 18.98$, $p < .0001$.

Design and procedure. Each child was evaluated with the WISC-III and the WRAT-R by licensed personnel from the school district. Each participant completed separate pretests on the fact series of 0 to 9 for multiplication, division, subtraction, and addition as a part of normal classroom assessment 2 weeks prior to the beginning of the study. Participants were given 1 hr to solve each pretest and were permitted to read nonrelated class materials quietly if they completed the pretest before the end of the assigned time period. Participants were not permitted to ask questions during the pretests which were completed in a counterbalanced order, with no more than two pretests completed per day.

Materials. Fact series (0 to 9) for the operations of addition, subtraction, division, and multiplication served as test stimuli. Materials included 3- x 5-in index cards for the presentation of each member of the fact series, with four solutions (marked A, B, C, D) presented in multiple-choice format. For each member of the fact series there was one card (e.g., 4 x 0) and four solutions to select among. The solutions were presented in multiple-choice format (e.g., A = 4, B = 8, C = 2, D = 0), with the solutions for each member of the fact series printed on separate index cards. Responses were recorded on either Scantron answer sheets or on the IF AT form.

Design and procedure. A latin squares procedure was used to determine the counterbalanced order of arithmetic operations that each participant was to complete during 30 consecutive sessions. The first 5 sessions served as a measure of baseline performance, and they were presented at the rate of 1 session per day with all responses recorded on Scantron forms. Prior to each baseline session, participants received additional instruction on the concept and function of the arithmetic operation currently being presented. Participants were then assigned to either one of the three feedback conditions or to the control condition for one of the arithmetic operations. The next 20 sessions consisted of one presentation of the fact series of 0 to 9, with no more than 2 sessions completed per day. The final 5 sessions served as a measure of maintenance, were presented at the rate of 1 session per day, and consisted of all participants completing the fact series in the absence of feedback and recording their responses on Scantron forms. Upon the completion of the maintenance sessions, participants were then assigned to the next arithmetic operation and into either a different feedback condition or to the control condition. Testing continued in this matter until each participant completed the four arithmetic operations.

Answers in the control condition were recorded with a pencil on a Scantron form. Answers in the delayed feedback condition were recorded on a Scantron form, but at the completion of the test session, all pencils were removed and the participants were permitted to review the fact series, the correct solutions, and their original answers for 30 minutes; these participants could review their work, but they could neither discuss it with other participants nor ask questions about their solutions. Participants in the other conditions remained seated during this time and worked quietly on noncourse materials under educator supervision. Participants receiving immediate feedback with the IF AT form scraped off the opaque, waxy coating covering an answer space on the IF AT form to record each answer. If a symbol (e.g., a star) was printed beneath the covering the student received instant feedback that a correct choice had been made; the absence of a symbol provided instant feedback that an incorrect choice had been made and that a selection from the remaining answers should be made. Answers in the educator feedback condition were recorded on a Scantron form, and verbal feedback was provided by the educator. Correct responses were reinforced with, for example, "that is correct, 4 x 1 is 4"; incorrect responses were met with, for example, "that is not correct" and a verbal prompt to make an additional response. A maximum of two additional responses was permitted before the correct solution was provided by the educator, and thus the maximum number of responses permitted and the performance information provided in the IF AT and educator conditions was comparable.

The number of correct first responses was averaged over the baseline sessions, with similar averages calculated, separately, for intervention and maintenance. These averages are hereafter referred to as mean accuracy, with scores during the maintenance sessions serving as the primary measure of retention.

Results

No difference was observed on any dependent measure as a function of sex of participant, random assignment within the MLD and NA groups to either an experimental or a control condition, and the counterbalanced order within which the arithmetic operations were presented, all $F < 1$, all $p > .5$. In the analyses described below, all data were aggregated across sex of participant.

Table 2

Mean Accuracy on Addition Fact Series Prior To and After Intervention in Study 1

	Math Difficulties								Normally Achieving							
	Before Intervention				After Intervention				Before Intervention				After Intervention			
	Ed	Im	Del	Con	Ed	Im	Del	Con	Ed	Im	Del	Con	Ed	Im	Del	Con
0	65	66	62	63	92	95	60	61	100	100	100	100	100	100	100	100
1	62	60	61	58	93	94	57	55	100	100	100	100	100	100	100	100
2	59	60	62	60	91	92	50	48	100	100	100	100	100	100	100	100
3	55	61	63	60	88	89	58	57	100	100	100	100	100	100	100	100
4	52	50	57	49	86	88	52	46	92	92	90	88	100	100	88	85
5	45	43	45	46	82	81	43	44	90	93	92	86	100	100	87	89
6	40	42	43	45	81	80	38	47	85	88	84	86	100	100	81	82
7	38	40	37	33	76	75	40	36	81	78	79	82	100	100	76	79
8	30	28	34	29	71	72	34	31	78	75	73	72	99	66	69	67
9	17	24	19	22	68	70	17	26	74	71	69	72	98	97	65	70

Note. Ed - feedback provided orally by educator; Im - feedback provided via an IF AT Form; Del - feedback provided at the end of the test; Con - control condition with answers recorded on Scantron forms.