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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

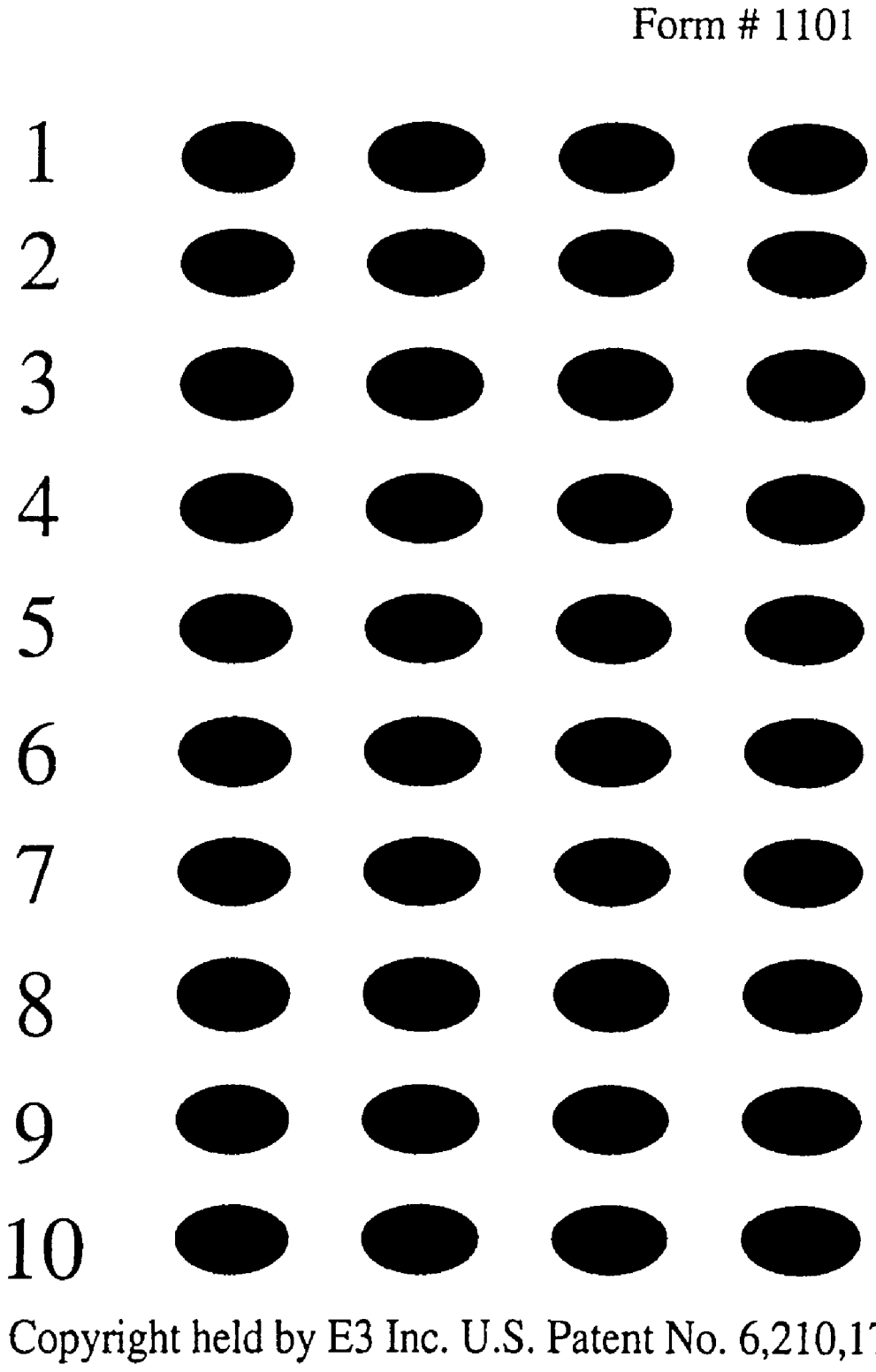

Figure 1. Sample portion of the Immediate Feedback Assessment Technique (IF AT) form. Patent is held by E3 Corporation.

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.

Table 3

Mean Accuracy on Subtraction 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	78	77	79	82	100	100	80	76	100	100	100	100	100	100	100	100
1	75	74	73	76	100	100	70	77	100	100	100	100	100	100	100	100
2	72	72	74	77	100	100	73	71	100	100	100	100	100	100	100	100
3	68	65	62	70	96	97	60	66	93	90	93	96	100	100	90	89
4	65	66	60	69	91	88	58	63	89	90	87	85	100	100	88	86
5	50	47	45	51	87	89	48	50	86	84	85	81	92	97	83	73
6	48	51	47	46	81	80	39	42	85	83	87	81	93	92	83	78
7	34	32	29	26	76	73	27	28	85	80	79	82	91	94	76	78
8	21	23	22	18	73	74	20	15	81	77	80	83	95	95	77	82
9	15	13	16	10	60	63	28	24	69	64	65	70	91	89	66	71

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.

Performance across the four arithmetic operations. Potential differences in mean accuracy (see Tables 2-5) were examined using separate analyses of variance for each arithmetic operation with experimental condition (educator, IF AT, delayed feedback, Scantron) and diagnostic group (MLD, NA) as between-subject factors and experimental period (baseline, intervention, maintenance) as the within-subjects factor. Significance was observed for each main effect and their interaction, all $F > 8.02$, all $p < .005$; the commonality of outcomes enables the integrated presentation of results. Scheffe comparisons for each arithmetic operation indicated that mean accuracy was (a) highest for the NA group and (b) higher within the MLD and NA groups for participants provided with immediate rather than with delayed feedback or a Scantron form, all $p < .005$. Scheffe comparisons within the NA group during addition, subtraction, and multiplication indicated that mean accuracy (a) did not

Table 4

Mean Accuracy on Multiplication 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	34	41	37	42	93	92	43	40	100	100	100	100	100	100	100	100
1	31	35	39	30	96	90	38	32	100	98	99	100	96	100	97	96
2	43	30	34	40	88	81	30	37	96	100	100	98	100	99	98	99
3	37	31	35	38	87	85	33	35	94	98	100	100	100	97	99	100
4	23	23	26	22	78	73	23	20	83	84	79	80	100	100	84	75
5	21	18	24	21	75	76	22	23	78	76	79	81	100	100	83	77
6	18	15	12	16	79	72	14	18	82	75	79	80	100	100	83	79
7	15	21	16	13	71	72	12	15	72	70	74	77	99	98	73	72
8	13	17	11	9	70	68	12	5	70	67	69	72	95	92	66	69
9	6	4	8	5	68	65	7	6	54	51	57	53	87	89	52	50

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.

differ between the future experimental and Scantron conditions on each fact series during baseline and on fact series 0 to 3 after the feedback and control conditions were introduced, all $p > .5$, and (b) was higher on fact series 4 to 9 for the educator and IF AT conditions than for the delayed feedback and Scantron conditions, all $p < .005$. Scheffe comparisons within the NA group during division indicated that mean accuracy (a) did not differ between the future experimental and Scantron conditions on each fact series during baseline and on fact series 0 after the feedback and Scantron conditions were introduced, all $p > .5$, and (b) was higher on fact series 1 to 9 for the educator and IF AT conditions than for the delayed feedback and Scantron conditions, all $p < .005$. Scheffe comparisons within the MLD group during the four operations indicated that mean accuracy (a) did not differ between the future experimental and Scantron conditions on each fact series during baseline, all $p > .5$, and (b) was higher on each fact series for participants receiving feedback from either an educator or the IF AT than for participants receiving either delayed feedback or a Scantron form, all $p < .005$.

Table 5

Mean Accuracy on Division 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	21	19	16	22	81	83	12	16	94	98	95	96	100	100	93	98
1	24	18	16	21	77	78	14	15	89	85	86	87	100	100	85	85
2	20	22	18	16	76	78	11	13	85	88	84	85	97	95	80	80
3	17	19	12	10	74	72	13	12	84	87	82	84	97	98	77	78
4	15	13	14	10	67	63	13	9	84	81	86	83	97	94	84	79
5	11	10	13	9	66	61	10	7	86	84	85	81	95	97	83	73
6	8	12	9	4	58	63	6	4	80	78	83	76	96	90	84	70
7	6	10	7	5	55	56	6	3	68	64	68	61	97	95	60	56
8	3	6	0	1	53	57	5	0	64	63	66	69	96	94	58	64
9	0	3	3	0	55	53	0	1	50	48	53	46	98	83	50	39

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.

Study 2: Effects of Feedback on the Acquisition and Retention of Arithmetic Fact Series: Reversing the Effects of Ineffective Feedback

Rationale. The results described above for each arithmetic operation demonstrate the efficacy of immediate feedback to facilitate the acquisition of fact series, and that the magnitude of this effect did not differ between the two sources of feedback: educator and IF AT form. The robustness of this effect was further examined for each arithmetic operation by retesting the participants receiving either delayed feedback or a Scantron form in Study 1, with one half of these participants receiving immediate feedback from an educator and the remaining half from the IF AT.

Method

Participants. The MLD participants were the same as those described above in Study 1. There were no differences in either WISC-III full-scale and subscale scores or WRAT-R standard scores as a function of experimental condition, all $F < 1$, all $p > .5$.

Materials. The materials were identical to those described above in Study 1.

Design and procedure. Performance on the arithmetic operation was examined during five baseline sessions, with no more than one session conducted per day. Prior to each baseline session, participants received additional instruction on the concept and function of the arithmetic operation currently being presented. One half of the participants, evaluated in Study 1 with either delayed feedback or a Scantron from, completed the first 20 intervention sessions using the same delayed feedback and Scantron conditions described in Study 1; the remaining half completed their calculations with immediate feedback provided by either an educator or the IF AT. A 5-session maintenance period was then imposed, with no more than one session conducted per day, to examine the short-term maintenance of learning. One half of the participants receiving either delayed feedback or a Scantron form during the first intervention period were provided with immediate feedback from an educator during the second intervention period, with the remaining half receiving feedback from the IF AT. Upon the completion of the second intervention period, an additional five maintenance sessions were completed. Participants provided with immediate feedback during the first intervention period completed the second intervention period using only Scrantron forms.

Results

No difference was observed on any dependent measure as a function of sex of participant, random assignment within each arithmetic operation to either an experimental or the 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.

Performance across the four arithmetic operations. Potential differences in mean accuracy (see Figures 2 and 3) were examined using separate repeated-measures analyses of variance with experimental condition (educator, IF AT, delayed feedback, Scantron) and experimental period (baseline, intervention, maintenance, intervention, maintenance) as within-subject factors. Significance was observed for each main effect and interaction, all $F > 9.66$, all $p < .005$; the commonality of outcomes enables the integrated presentation of results. Scheffe comparisons indicated that mean accuracy (a) did not differ between the future experimental and control conditions at baseline, all $p > .5$, (b) was significantly higher for participants receiving immediate feedback from either an educator or the IF AT during the first intervention period than for participants receiving either delayed feedback or a Scanton form, all $p <$

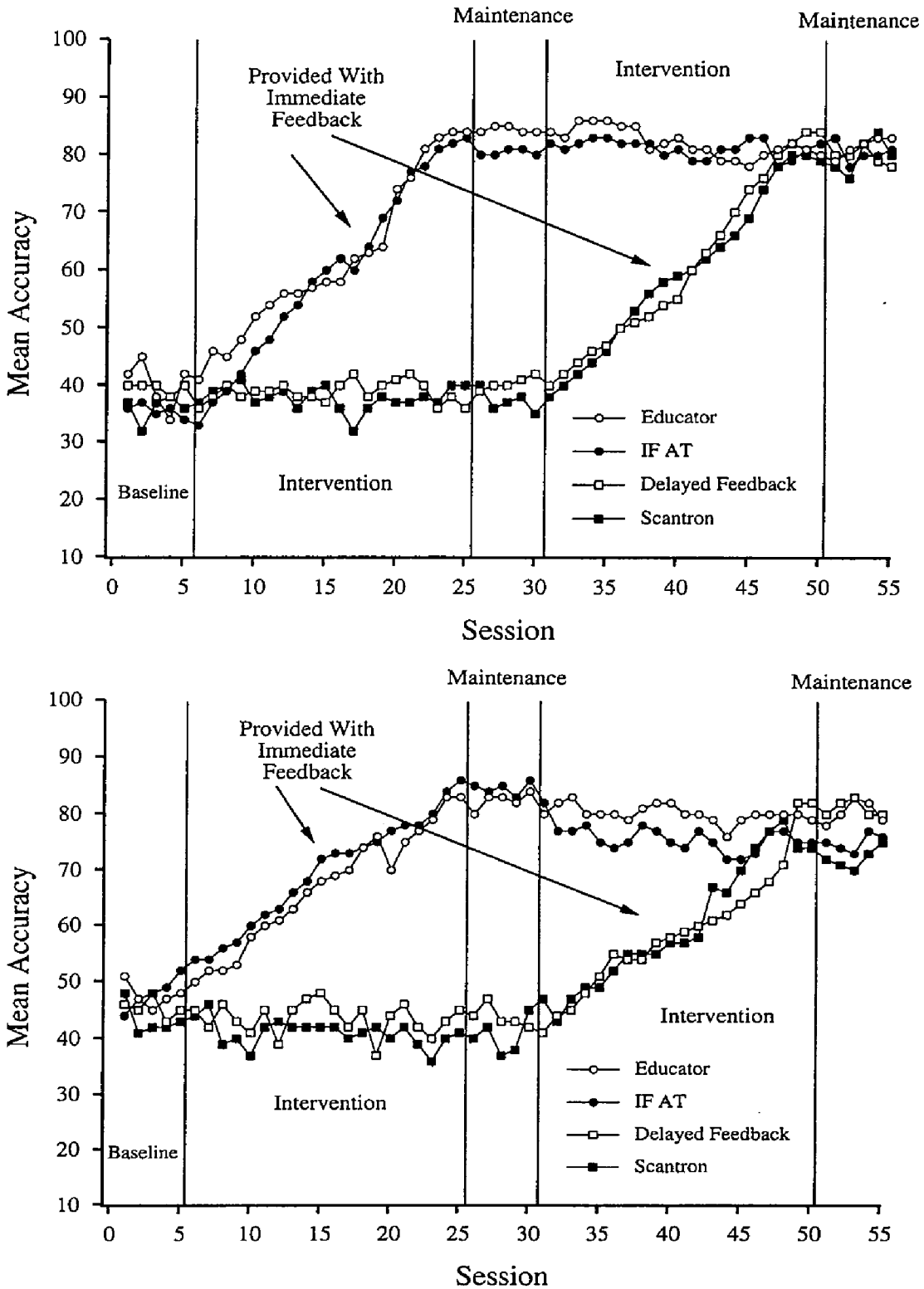

Figure 2. Mean accuracy on the fact series for addition (top panel) and for subtraction (bottom panel) as a function of feedback condition and experimental phase in Study 2.

.005, (c) increased significantly for participants switched from the delayed feedback and Scantron conditions to immediate feedback during the second intervention period, all $p < .005$, and (d) did not differ between the groups during the second maintenance period, all $p > .5$.

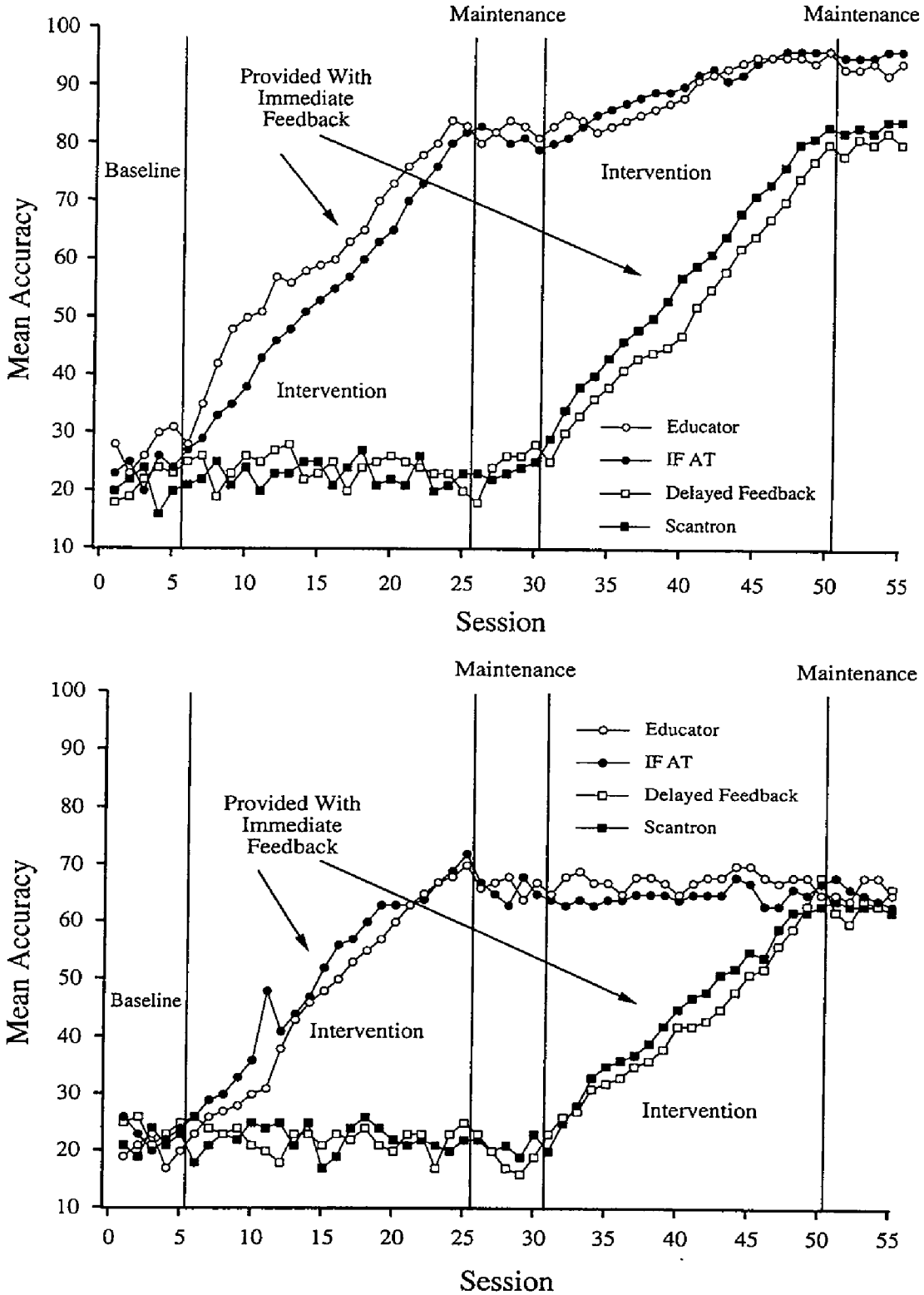

Figure 3. Mean accuracy on the fact series for multiplication (top panel) and for division (bottom panel) as a function of feedback condition and experimental phase in Study 2.

Study 3: Potential Roles For Visual, Auditory, and Combined Visual-Auditory Feedback on the Acquisition and Retention of Arithmetic Fact Series

Rationale. The acquisition and retention of arithmetic fact series

for the operations of addition, subtraction, multiplication, and division in Studies 1 and 2 did not differ as a function of source of feedback: educator or IF AT. In both studies, the provision of delayed feedback was no more effective than control procedures. Study 3 was undertaken to compare the effectiveness of the auditory feedback provided by an educator and the visual feedback provided by the IF AT form with the combined visual and auditory feedback provided by the Write-Say method (e.g., Lombardo & Drabman, 1985). The Write-Say method has been reported to be highly effective for instructing students with learning disabilities, with the primary effect attributed to the use of two sensory modalities during the acquisition process. Given the lack of effect observed in Studies 1 and 2 for delayed feedback, this procedure was not included in Study 3.

Method

Participants. Participants included 25 male and 15 female students enrolled in 3rd grade classes at an urban elementary school and classified with a learning disability in mathematics (MLD), none of whom had prior experience with educational interventions that included either immediate feedback or the Write-Say method. The diagnostic procedures were the same as those described above in Study 1. The representative MLD participant was identical to that described in Study 1; all parents expressed concern over their children's academic performance and the quality of instruction they received. Potential differences in WISC-III (FSIQ, Verbal, Performance) and WRAT-R standard score (reading, spelling, arithmetic) did not differ as a function of (a) sex of participant, (b) random assignment to either an intervention or the control group, and (c) the counterbalanced order in which the arithmetic operations were presented, all $F < 1$, all $p > .5$. Descriptive statistics for WISC-III and WRAT-R scores are presented in Table 6.

Table 6

Means and Standard Deviations for WISC-III and WRAT-R Standard Scores in Study 3

	Math Difficulties		Normally Achieving	
	M	*SD*	*M*	*SD*
WISC - III				
FSIQ	89.56	16.43	90.12	15.98
Verbal	90.42	14.26	89.34	14.39
Performance	89.56	12.35	91.04	15.93
Reading SS	89.44	14.82	88.17	15.64
Spelling SS	90.01	13.78	89.83	14.68
Arithmetic SS	63.55	10.44	88.09	14.69

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

Materials. The materials were identical to those described above in Study 1 for the control and both immediate feedback conditions. Participants in the Write-Say condition were provided with a tablet of lined writing paper.

Design and procedure. The baseline, intervention, and maintenance periods and the educator, IF AT, and Scantron conditions were the

same as those described in Study 1. The participants in the Write-Say condition were evaluated by blending the procedures of the educator and IF AT conditions with those traditionally used in the Write-Say method. Accordingly, when a correct response was made, the educator provided affirming feedback, and the participant continued to the next problem. When an incorrect response was made, the educator indicated that the response was incorrect, and that the participant should review the problem and remaining options and to continue to select answers until correct. Once the correct answer was discovered, the problem and its correct answer

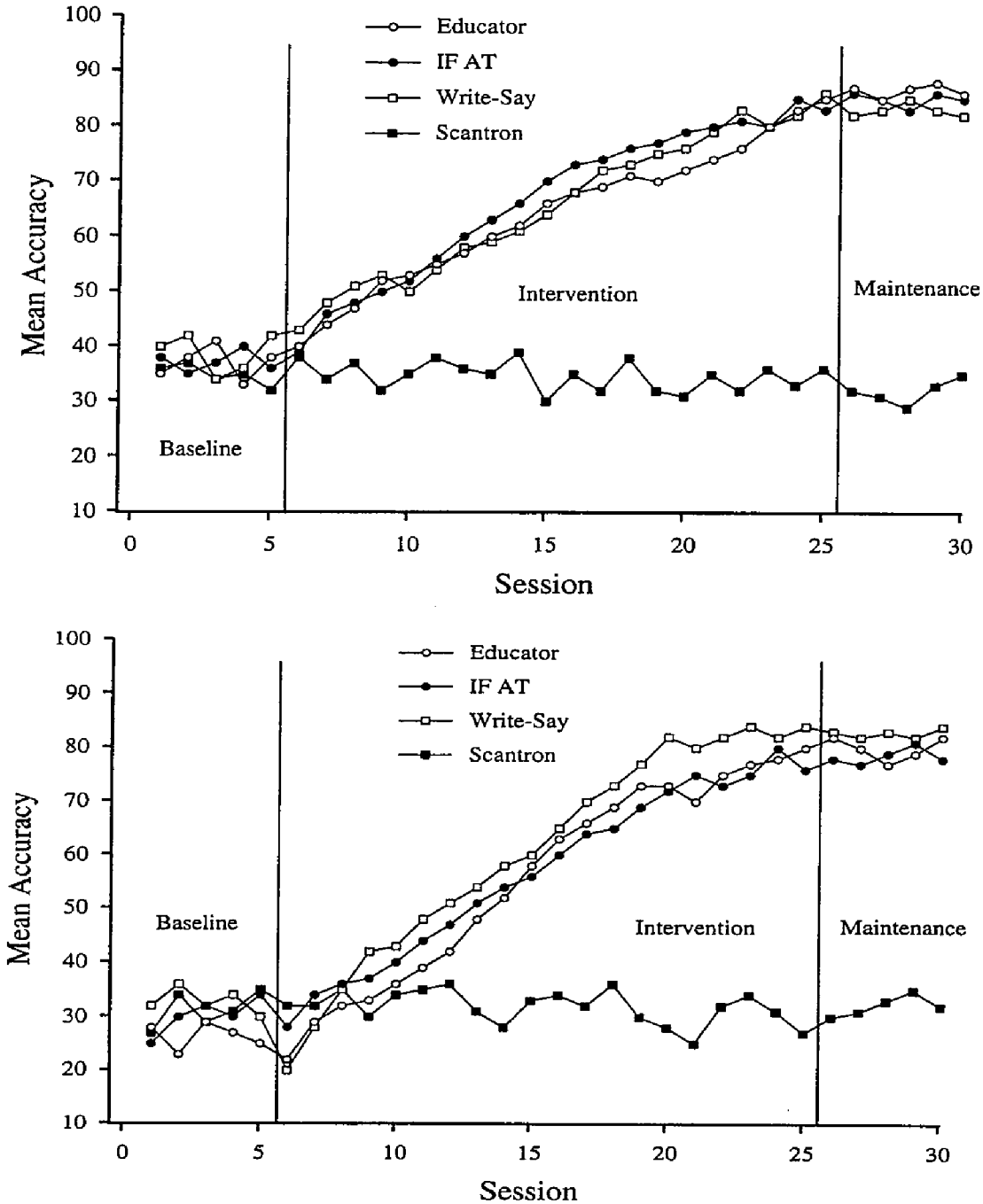

Figure 4. Mean accuracy on the fact series for addition (top panel) and for substraction (bottom panel) as a function of feedback condition and experimental phase in Study 3.

were written five times on the tablet and repeated orally an equal number of times. The latin squares procedure described in Study 1 was used to counterbalance the order of the arithmetic operations each participant was to complete. Upon the completion of these procedures, participants were assigned to the next arithmetic operation and to either a different experimental condition or to the control condition. Testing continued in this matter until each participant completed the four arithmetic operations, one in accordance with the control and each experimental condition.

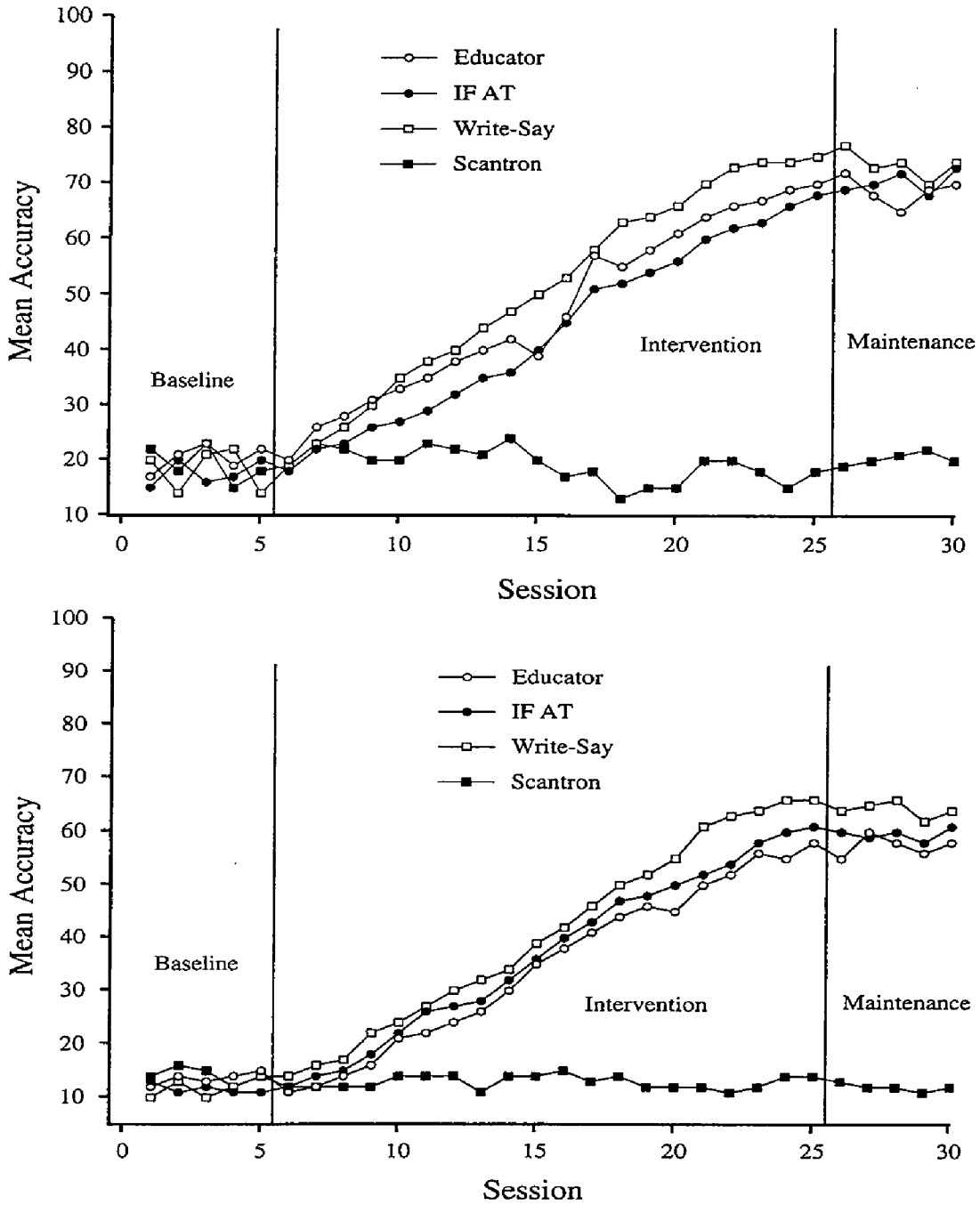

Figure 5. Mean accuracy on the fact series for multiplication (top panel) and for division (bottom panel) as a function of feedback condition and experimental phase in Study 3.

Results

No differences were observed on any dependent measure as a function of (a) sex of participant, (b) random assignment to either an intervention or a control procedure, and (c) the counterbalanced order in which the arithmetic operations were presented, all $F < 1$, all $p > .5$.

Performance for the four arithmetic operations. Potential differences in mean accuracy (see Figures 4 and 5) were examined using separate analyses of variance with experimental condition (educator, IF AT, Write-Say, Scantron) as the between-subjects factor and experimental period (baseline, intervention, maintenance) as the within-subjects factor, with significance observed for each main effect and their interaction, all $F > 8.44$, all $p < .001$. Scheffe comparisons for the four arithmetic operations indicated that mean accuracy (a) did not differ between the future experimental and control conditions at baseline, all $p > .5$, (b) was significantly higher for participants receiving immediate feedback from an educator, the IF AT, or the Write-Say method during intervention than for participants receiving a Scantron form, all $p < .005$, and (c) did not differ between the educator, IF AT, and Write-Say conditions during maintenance, all $p > .5$.

Discussion

The participants classified with math disabilities were identified by their classroom and resource room educators for inclusion in Studies 1-3, as each student during the preschool through 2nd grade years had demonstrated marked difficulty with basic arithmetic computations. The participants in the normally achieving group were matched to those in the math disabilities group on the basis of WISC-III scores, standard scores for reading and spelling on the WRAT-R, and general measures of classroom performance (e.g., absences, overall GPA, and participation). Participants with ADHD or comorbid reading disabilities (Jordan, Kaplan, & Hanich, 2002) were not included in Studies 1-3, as the performance of such participants is substantially different from that of children classified exclusively with a math disability (Seidman, Biederman, Monuteaux, Doyle, & Faraone, 2001).

The consistent outcome of Studies 1-3 is that the provision of immediate, affirming, and corrective feedback facilitates the acquisition and retention of fact series across the four arithmetic operations. The source of feedback: educator or IF AT, did not differentially affect learning, and in Study 3, there was no interactive effect of combining the auditory feedback of the educator and the visual feedback of the IF AT with the requirement that initially incorrect problems be written and spoken. It should be noted, however, that the traditional procedures used to define the Write-Say method were modified in Study 3 in order to equate the auditory feedback with that of the educator condition and the visual feedback of the IF AT condition. The results of follow-up tests conducted in our classrooms and laboratories replicated the outcomes of Study 3 when either the

traditional or the modified Write-Say method was used. The salience of immediate feedback remained apparent beyond the stage of acquisition, with continued accessibility of the fact series readily demonstrated during the 1- to 5-week-long maintenance periods. The continued accessibility of the fact series was evident when MLD participants completed the fact series for each arithmetic operation in the absence of feedback 3 and 6 months after completing maintenance (see Figure 6).

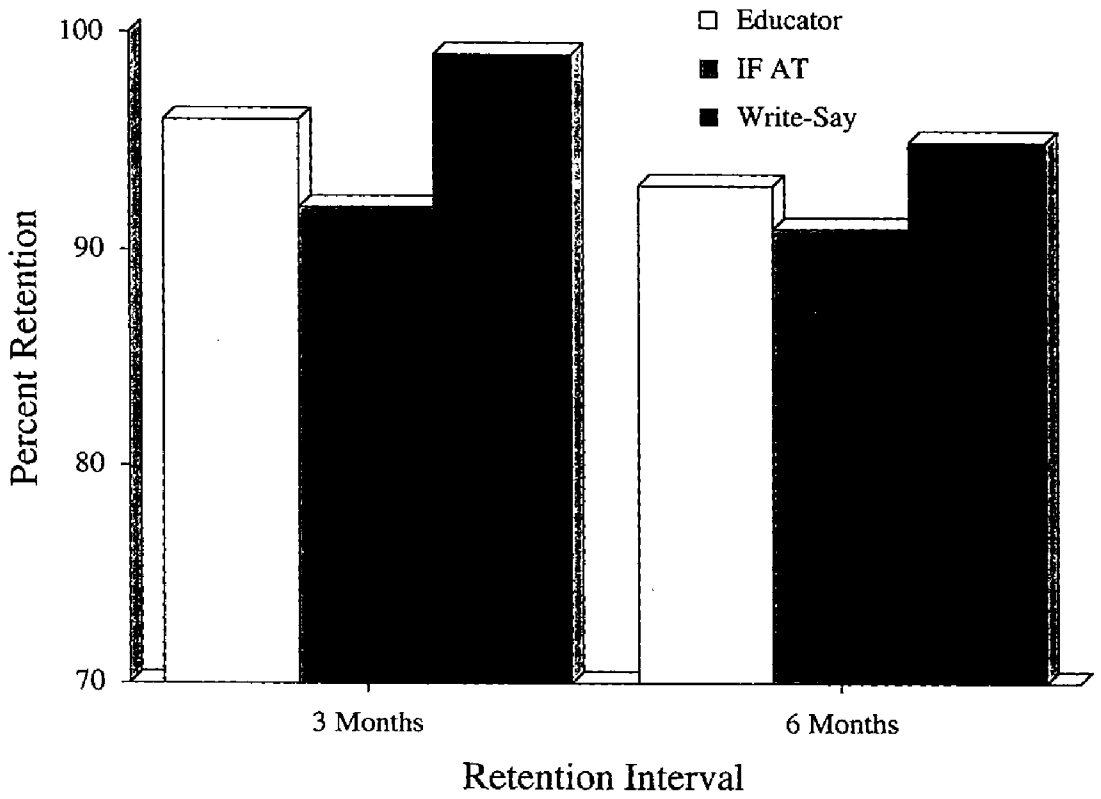

Figure 6. Mean retention rates (relative to maintenance levels) plotted as a function of experimental condition and retention interval.

It should be noted that while the immediate feedback provided in the present studies enhanced participants' acquisition of fact series, similar gains were not observed in how the participants applied their knowledge of the fact series during follow-up tests. This conclusion is supported through examination of participants' strategies conducted prior to the beginning of Study 1 and upon the completion of the retention tests described above using procedures described previously (Geary & Brown, 1991). Students with math disabilities continue to rely upon counting strategies (i.e., finger counting) during Studies 1-3, at the rate of approximately 70% whereas normally achieving students decreased their use of similar strategies from 40% to less than 10%; these rates are similar to previously reported values (e.g., Siegler, 1986). Similar observations have been reported in longitudinal studies in which normally achieving children increase reliance on memory retrieval and decrease reliance on counting to solve the addition problems (Geary & Brown, 1991). Fact-retrieval deficits in children with math disabilities have been reported to persist throughout

elementary school, and in some studies the percentage of trials in which children with math disabilities used retrieval for number facts remained flat (i.e., direct retrieval was used on less than 5% of trials) whereas normally achieving children typically increase their rate of direct retrieval to 50% (e.g., Ostad, 1999).

The special-needs classroom places heavy demands on teachers to monitor performance and to provide feedback, especially when research suggests that feedback is most effective when it is provided immediately. The failure of students with math disabilities to develop and execute strategies with which to increase computation accuracy suggests that special education and regular education classrooms must develop new instructional techniques that can be directly applied to enhance student performance (National Council on the Teaching of Mathematics, 2000). The provision of corrective information is not a new pedagogical procedure, but it is one that can be simply and easily applied in special education and regular education classrooms. The delivery of feedback by an educator, on a one-on-one basis, requires either a considerable number of paraprofessionals or the distribution of short sessions of feedback across an extended period of time. The IF AT enables the provision of feedback on a one-to-one basis, and it does so at a comparatively nominal cost. The IF AT supports learning by providing immediate affirming and/or corrective feedback while involving the learner in the discovery process, and to those ends, the answer-until-correct procedure described in the present study is presented as a tool for use in educational settings where one-to-one educator oral feedback is impractical.

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