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Computer-Assisted Instruction With Constant Time Delay to Teach Multiplication Facts to Students With Learning Disabilities

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The effectiveness of a computer software program using the constant time delay procedure to teach multiplication facts was investigated in this study. Six male elementary school students with learning disabilities, between the ages of 9 and 10 years old (three of whom also had been diagnosed as having attention deficit disorders), were taught 15 unknown facts using an auto-instructional program based on a 5-sec constant time delay procedure. Data were collected on generalization to a vertical display format, which required a written response, the reverse fact, and a flashcard presentation to which students made a verbal response. Results indicate that the computer-assisted instructional program was effective in teaching multiplication facts to students with learning disabilities. Learning generalized with varying degrees of success for the different students.

The development of automaticity with basic facts is considered by many educators to be essential to learning more advanced mathematical skills (Pressley, 1986). Students who demonstrate learning disabilities (LDs) often have more difficulty than their nonhandicapped peers in acquiring and becoming fluent with these facts (Fleischner, Garnett, & Shepherd, 1982; Goldman, 1989). In particular, students with LDs frequently find the multiplication facts to be a stumbling block in their mathematical progress due to the inefficiency and inaccuracy of counting methods and their difficulties with memorizing multiplication tables (Koscinski & Gast, in press; Lombardo & Drabman, 1985). Fleischner et al. (1982) evaluated the performance of 183 children with LDs and 842 children without LDs on their proficiency with basic addition, subtraction, and multiplication facts. Their results indicate that students with LDs attempted fewer problems in the allotted time (computational speed), were less accurate, and were more variable in their proficiency (percentage correct of the number of problems attempted) than their peers without LDs. Various suggestions have been made to explain this disability in students with LDs. Difficulties with psychomotor speed (Fleischner et al., 1982), visual or auditory perceptual deficits (Lombardo & Drabman, 1985), memory deficits (Cordoni, 1987), and difficulties developing automaticity by shifting from reconstructive (counting) to direct retrieval strategies (Fleischner et al., 1982; Woodward, 1991) have been cited as possible explanations. Due to the basic multiplication fact deficits often seen in these children, one primary instructional goal is often the development of automaticity with those facts.

In a review of the research literature concerning mathematics instruction, Mastropieri, Scruggs, and Shiah (1991) found that all procedures studied were judged to be effective by the authors. These strategies included reinforcement, goal setting, specific strategies for computation and problem solving, mnemonic strategies, peer mediation, and computer-assisted instruction (CAI). Facility with multiplication facts has been fostered through the use of flashcards and multiplication charts (Remington, 1989), the number line (Kurland, 1990), Cuisenaire rods, Stern materials, Dienes Multi-Base Arithmetic Blocks, and Fingermath (Lamon & Lieberthal, 1982). Others have reported success with principal-implemented testing, feedback, and reinforcement (Brown, Copeland, & Hall, 1986); Write and Write–Say procedures (Lombardo & Drabman, 1985); the use of count-bys (McIntyre, Test, Cooke, & Beattie, 1991); and the use of card games (M. D. Campbell, 1989). Researchers of students with mild handicaps have investigated the effectiveness of strategy instruction and self-instruction (Goldman, 1989; Leon & Pepe, 1983) in improving mathematical computation performance. The use of systematic instruction with almost errorless teaching procedures, such as constant time delay, to facilitate acquisition of and fluency with multiplication facts also has been investigated (Cybriwsky & Schuster, 1990; Koscinski & Gast, in press; Mattingly & Bott, 1990).

Constant time delay is an instructional procedure that provides for the systematic introduction of teacher assistance. This near-errorless technique employs a controlling prompt to ensure the successful performance of the student (Gast, Wolery, Ault, Doyle, & Alig, 1988; Stevens & Schuster, 1988). In general, the procedure involves the presentation of a stimulus (e.g., a word or math fact), after which the student is allowed a specific amount of time (e.g., 3 sec) to provide the correct answer (e.g., read the word or answer the fact). If the student does not respond within the time allowed, a controlling prompt, typically a teacher modeling the correct response is provided. The controlling prompt is a cue that ensures that the student will respond correctly (e.g., the word name or the answer to the problem is modeled). The student then repeats the teacher's model. Correct responses before or after the prompt are reinforced; however, only correct responses before the prompt count toward criterion. The effectiveness of the constant time delay proce-

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dure has been demonstrated with a variety of academic skills, students, and instructional arrangements (Schuster, Stevens, & Doak, 1990; Stevens & Schuster, 1987; Wolery, Cybriwsky, Gast, & Boyle-Gast, 1991). Three studies have described its effectiveness in teaching multiplication facts to students with mild LDs (Cybriwsky & Schuster, 1990; Koscinski & Gast, in press; Mattingly & Bott, 1990). None of these studies used a CAI format. The constant time delay procedure, however, has been used in a computer software program to teach spelling skills (Kinney, Stevens, & Schuster, 1988). Under a grant from the U.S. Department of Education, Blackhurst and Stevens, at the University of Kentucky, are developing a series of software programs based on the constant time delay procedure called *Waiting to Learn* (D. L. Gast, personal communication, December 23, 1991).

CAI has received much attention in the literature as a means to improve mathematical as well as other academic skills. The use of computers in the classroom has been viewed as a management tool, an instructional aid, and a content of instruction in itself (Ross, 1991). According to Roblyer (1985), one commonly held belief is that "computers make possible unique learning conditions, resulting in greater gains than were previously possible" (p. 41). They can provide clarification of concepts, independent and guided practice, student motivation (Malouf, Jamison, Kercher, & Carlucci, 1991a, 1991b), and, in general, a flexible tool to achieve a variety of goals (MacArthur & Malouf, 1991).

Researchers investigating CAI have focused on several areas, including academic achievement, motivation, and attention to task. Results in the area of improvement in academic achievement have been remarkably variable (Woodward & Carnine, 1988). Bahr and Rieth (1989) cited several studies comparing achievement gains using CAI to those involving traditional instruction with special education students. They stated that some showed CAI to be superior, some indicated the superiority of traditional instruction, and some showed no difference. In their review of the literature, Iacono and Miller (1989) reported similarly variable results with special education populations. Howell, Sidorenko, and Jurica (1987) investigated the effectiveness of a drill-and-practice computer program on the multiplication performance of a student with LDs. Their results indicated an initial, but transitory effect on the student's response time and number of errors. In comparing multiplication achievement following CAI or paper-and-pencil practice for achievers and underachievers, McDermott and Stegeman (1987) reported results favoring CAI instruction for both groups of students. Chiang (1986) found no advantage of a computer multiplication game over flashcards with six students with LDs. Bahr and Rieth (1989) and Christensen and Gerber (1990) reported the advantage of drill-and-practice over game-format software in improving the achievement of students with LDs with basic facts.

The variable results of the research on the effectiveness of CAI on academic achievement have led to the suggestion that software design may be the determining factor in using CAI to improve academic skills with mildly handicapped students (Bahr & Rieth, 1989). To promote automaticity, researchers have suggested incorporating a large number of responses, a rapid pace, and controlled response times into the design (Hasselbring, Goin, & Bransford, 1988; Malouf et al., 1991b). Perkins (1988) cautioned that producing too many errors may frustrate students and cause them to become less engaged in the CAI task. Malouf et al. (1991a) suggested that teachers use an authoring tool to develop suitable software for their students. There is consistent agreement that software design should be based on sound, proven learning principles (Majsterek & Wilson, 1989; McDermott & Stegeman, 1987; Price, 1989).

The purpose of our study was to investigate the effectiveness of a software program incorporating the constant time delay instructional procedure to teach multiplication facts to six elementary-age students with LDs. The research question was as follows: Will a computer software program, which uses a constant time delay procedure, be an effective strategy for teaching multiplication facts to students with LDs?

METHOD

Subjects

Six male students (Tommy, Charlie, Jimmy, Bill, Danny, and Bob), enrolled in a rural, public elementary school, participated in the investigation. The students were evaluated by the local school system and determined to be eligible for LDs placement. In addition, three students (Tommy, Jimmy, and Bob) had been diagnosed as exhibiting characteristics of an attention deficit disorder and were being treated with stimulant medication. All three were taking Ritalin or a similar generic. Tommy's dosage was 5 mg, twice a day; both Jimmy and Bob took 10 mg, twice a day. After initial services via a resource delivery system, the students had been placed in a self-contained setting. All students were mainstreamed for one period per day and for nonacademic activities, such as homeroom, lunch, and recess. The students ranged in age from 9 to 10 years old and were mainstreamed into third- or fourth-grade classrooms. Their full scale IQ scores on the Wechsler Intelligence Scale for Children–Revised (WISC–R; Wechsler, 1974) ranged from 71 to 101. The students had some previous experience with teacher-directed constant time delay instruction: Charlie had been taught numerals up to 20 during the fall of the school year that this study took place, and all six students had been taught the 0, 1, and 2 times tables during the month prior to Christmas vacation. In addition, all students were somewhat familiar with the computer used in the study and with reading and mathematics software programs, in general. They could access programs on the hard drive, follow general directions for progressing through a program, and close the program on completion. Detailed information for each student is presented in Table 1.

Each student's individual education plan included a short-term objective concerning the acquisition of the multiplication facts. They had been instructed in the multiplication concept, multiplication as repeated addition, the commutative property of multiplication, and the rules for the 0 and 1 times tables. Bob had been trying to learn the multiplication facts for more than 1 year using traditional instructional approaches and approximately 1 month of teacher-directed instruction using the constant time delay procedure. The other students had only the constant time delay instruction for

TABLE 1
Descriptions of Six Subjects

Subject	*Age*	*Grade*	*Sex*	*FSIQ*[a]	*VIQ*[b]	*PIQ*[c]	*Math*[d]
Tommy	9	3	M	91	111	72	103
Charlie	10	3	M	78	81	78	82
Jimmy	9	3	M	101	92	112	105
Bill	9	3	M	84	84	87	103
Danny	10	3	M	71	84	63	82
Bob	10	4	M	100	97	104	89

[a]Full scale IQ on the WISC–R (Wechsler, 1974). [b]Verbal scale IQ on WISC–R. [c]Performance scale IQ on WISC–R. [d]Standard score on Basic Achievement Skills Individual Screener (The Psychological Corporation, 1983).

approximately 1 month. All students were able to calculate multiplication facts using counting methods when provided an unlimited amount of time for that calculation. However, they all had difficulty memorizing the times tables above 2 as evidenced by their performance on timed tests. This agrees with Cordoni's (1987) observation that most students with LDs have difficulty with memorizing multiplication tables. As evaluated prior to the initiation of the study, the students demonstrated the following prerequisite skills:

1. Sat and attended to a computer software instructional program for a maximum of 10 min.
2. Keyboarded the numerals represented in the multiplication tables through the 9 times tables.
3. Demonstrated an understanding of the multiplication concept by solving written multiplication problems when given no time restraints.
4. Demonstrated an understanding of the commutative property of multiplication (e.g., that 3 × 7 has the same answer as 7 × 3) by solving paired written problems with one answer provided.
5. Waited 5 sec for a visual model prompt to an unknown fact presented on the computer screen and then imitated the prompt after retyping the problem on the computer.

Setting

Screening, probe, and instructional sessions were conducted in the self-contained LDs classroom with the student seated at a computer table in a recessed area of the classroom. Approximately 20 students, the investigator (teacher), and two paraprofessionals were present in the classroom. The investigator was usually seated at a kidney-shaped table within 10 ft of the computer with a clear view of the computer screen. The paraprofessionals were usually across the room with no clear view of the screen. Besides the ordinary classroom management system involving the use of checks placed on a behavior card, contingent on acceptable behavior and redeemable for back-up reinforcers, no other means was used to manage student behavior. Other students were engaged in various independent or group activities under the supervision of the teacher and paraprofessionals.

Materials, Equipment, and Reinforcers

Multiplication facts used for screening unknown facts were obtained from a commercial set of flashcards with problems written in a vertical orientation. During probe and instructional sessions, a Macintosh LC computer with a 12 in. color monitor, a floppy disk drive, a hard drive, a printer, and appropriate software, developed by Koscinski (the first author) from Authorware Professional software (Authorware, Inc., 1990), were used.

During screening, reinforcement consisted of verbal praise for correct responses delivered by the instructor. During probe and instructional sessions, visual or visual and auditory reinforcement was provided by the software. In addition, checks on a behavior point card, which could be redeemed for gum, computer game time, or treats from the grab bag, were awarded after each session. The student's progress was also publicly posted on a graph display on the wall of the classroom.

Procedures

Screening. Screening for unknown facts was performed using flashcards presented by the teacher. The flashcards were shuffled to randomize the order of presentation. From these unknown facts, a pool was developed for use in the instructional phase of the study. All 100 fact problems were presented to the student during one session. A fact was considered to be unknown if the student did not name the correct answer within 5 sec after reading the problem aloud. These missed fact problems were used to form each student's pool of unknown facts. Fifteen unknown multiplication facts were divided into three sets of 5 facts each. The facts were ordered into sets in an attempt to reduce the number of similarities among facts within the same fact set (Graham, 1987; Koscinski & Gast, in press). This procedure was followed in response to research suggesting that similarities among problems within a fact set (e.g., 5 × 7 grouped in a set with 5 × 8) may interfere with a strong association being formed with the correct product (J. I. D. Campbell, 1987; McCloskey, Harley, & Sokol, 1991). Reverses of unknown facts were not included in probe or instructional sets of facts (e.g., if 3 × 7 was unknown, 7 × 3 was not included in a set even if it had been determined to be unknown). Each student's sets of facts targeted for instruction are presented in Table 2.

TABLE 2
Targeted Sets of Multiplication Facts

	Student					
Set	*Tommy*	*Charlie*	*Jimmy*	*Bill*	*Danny*	*Bob*
1	4 × 6	5 × 3	4 × 7	3 × 9	2 × 9	4 × 3
	8 × 7	4 × 4	3 × 6	7 × 6	7 × 5	8 × 8
	5 × 9	3 × 7	8 × 5	4 × 4	6 × 3	9 × 5
	5 × 5	6 × 5	9 × 6	8 × 5	4 × 8	3 × 7
	7 × 9	8 × 8	5 × 5	9 × 4	9 × 9	6 × 9
2	9 × 4	3 × 3	4 × 4	7 × 5	5 × 3	4 × 7
	6 × 6	6 × 9	6 × 5	3 × 8	2 × 4	3 × 6
	4 × 7	9 × 3	7 × 8	9 × 6	8 × 6	9 × 8
	5 × 6	4 × 5	9 × 4	8 × 4	7 × 2	7 × 6
	8 × 5	7 × 8	6 × 7	7 × 7	7 × 7	5 × 5
3	4 × 8	3 × 4	4 × 8	9 × 5	6 × 2	4 × 5
	5 × 7	9 × 9	7 × 5	6 × 8	5 × 8	3 × 8
	6 × 9	8 × 3	6 × 4	5 × 4	9 × 7	8 × 6
	9 × 9	4 × 6	7 × 7	7 × 4	3 × 9	9 × 9
	7 × 7	5 × 5	8 × 8	9 × 9	4 × 4	7 × 7

General procedures. All sessions were conducted individually and were auto-instructional; data were collected continuously during all phases of the study. A folder was created for each student on the hard drive. Into this folder the teacher placed the programs to be used by that student, with the one to be used for the next session outlined in color and positioned in the top left corner of the folder. Prior to each session, the teacher directed the student to the computer, observed the student accessing the correct program, then engaged in other activities unrelated to the CAI. One session was conducted each day, 4 days per week, until near the end of the school year, at which point sessions were increased to two per day, with at least a 1-hr break between sessions. The number of sessions per day was increased at that time to complete the study by the end of the school year.

The software program was designed to report data in two ways. Data were stored in a file on the hard drive. These data included student name, session date, beginning and ending times of the session, type of session (probe, instruction with Set 1, etc.), number of trials in the session, number of responses in each category (unprompted corrects, prompted corrects, etc.) as well as the percentage, number of errors of all types in the session, and the factors for each specific problem and type of response to that problem (e.g., "4 8 UC" indicated the problem 4 × 8 and an unprompted correct response). A sample of data from one session stored in the file is presented in Table 3. In addition, the student's performance was displayed on the screen following each probe or instructional session and was printed to provide a hard copy. The performance display included the student's name, type of session and fact set number, date, number of trials in the session, and total number and percentage of response types (Table 4). Specific data-collection procedures by condition are described in their respective sections.

Probe procedures. Probe sessions were conducted immediately prior to instruction with each fact set and immediately following the student's reaching intervention criterion with each set. During a probe condition, students were directed by instructions on the computer screen to type the factors for the problem, as an active, specific attentional response (Holcombe-Ligon, Wolery, & Werts, 1992), and then the answer if they knew it. Students were allowed 5 sec to respond with an answer before the screen was cleared and the next problem presented. The software program randomly selected the order of the problems from each set and then repeated the selection process once. Thus, each fact was presented twice during a probe session, for a total of 30 trials. During probe conditions, students' responses were scored as correct if they responded with the correct answer within 5 sec after correctly typing the problem and incorrect if they did not.

During probe conditions, students were reinforced on a continuous reinforcement (CRF) schedule for correct answers with visual and auditory effects presented by the program. Incorrect answers were ignored and the next trial presented. In addition, attention and effort were visually reinforced on the average of every fifth trial (VR–5) by an effect and positive message (e.g., "I like how you work!"). Following each probe session, the teacher placed a check on the point card for each correct answer.

Instructional procedures. During instructional conditions using the constant time delay procedure, the following directions appeared on one screen prior to the display of the first fact problem:

1. Copy each number in the problem, then press Return. (This requirement of a specific attentional response was included in order to focus the student's attention on the specific factors of the problem at hand.)

The screen displayed the problem in a horizontal orientation and underneath it an identical format with the factors deleted:

$$3 \times 7 =$$
$$\times \quad =$$

The cursor would blink at the spot requiring the first factor until it was entered correctly by the student, then jump to the spot requiring the second factor until it was correctly entered, and then jump to the product position at which point the delay interval was begun. If an incorrect factor was entered, the cursor would not jump to the new position, the factor was highlighted, and the message "Try again" was displayed on the screen.

2. Type the answer if you're sure you know it, then press Return.

TABLE 3
Sample of Data for Charlie Stored on Hard Drive

Charlie	4/24/92	BeginningTime=9:00 AM						Instructionwithsetnumber=2				
3	3	UC	7	8	PC	9	3	PC	4	5	PC	6
9	PC	9	3	PC	7	8	PC	6	9	NR	4	5
PC	3	3	UC	4	5	PC	3	3	UC	7	8	PC
9	3	NR	6	9	WE	4	5	PC	6	9	WE	7
8	NR	9	3	PC	3	3	UC	9	3	UC	7	8
PC	3	3	UC	4	5	PC	6	9	WE	7	8	PC
6	9	PC	4	5	PC	9	3	NR	3	3	UC	
EndingTime=9:10 AM				#oftrials=30			Errors=7		UC=7	PC=16		
NWE=0		WE=3	NR=4	PUC=23.3333333333				PPC=53.3333333333				
PNWE=0		PWE=10		PNR=13.3333333333								

Note. UC = no. of unprompted corrects; PC = no. of prompted corrects; NWE = no. of non-wait errors; WE = no. of wait errors; NR = no. of no response errors; PUC = % of unprompted corrects; PPC = % of prompted corrects; PNWE = % of non-wait errors; PWE = % of wait errors; PNR = % of no response errors.

TABLE 4
Sample of Student Performance Displayed on Computer Screen and Printed

Name: Charlie		Date: 5/18/92
Trials: 30		
Unprompted Corrects: 29	96.67%	
Prompted Corrects: 0	0%	
Non-wait Errors: 1	3.33%	
Wait Errors: 0	0%	
No Response Errors: 0	0%	
Set #: 2		

3. If you're not sure, wait and I'll tell you.

The software program randomly selected each of the 5 facts in the set and then repeated the process six times for a total of 30 trials per session. The first session for each new fact set employed a 0-sec delay: The prompt (the answer displayed on the screen) was presented immediately following the correct copying of the problem. All remaining sessions with that fact set were conducted at a 5-sec delay: The prompt was provided if the answer had not been typed by the student within 5 sec of his or her having copied the problem. This 5-sec delay was selected rather than the more common 3- or 4-sec delay to provide extra time for locating and typing numerals on the keyboard.

During constant time delay instruction, five response categories were used:

1. Unprompted correct (UC)—if the student responded correctly within 5 sec of typing the problem.
2. Prompted correct (PC)—if the student waited for the prompt and then typed the problem again and correctly typed the answer within 5 sec.
3. Non-wait error (NWE)—if the student incorrectly typed the answer to a fact problem within 5 sec of typing the problem.
4. Wait error (WE)—if the student waited for the prompt, but then incorrectly imitated it.
5. No response error (NR)—if the student failed to respond within 5 sec after typing the problem again following the prompt.

Only UC responses were used to determine criterion performance during instruction.

Reinforcement during instruction was on a CRF schedule for UC and PC responses until the student achieved 100% UC responses for two sessions. The schedule was then thinned to VR-5 until the 100% UC criterion was met during one session. UC responses were reinforced with visual (animated) and auditory effects (e.g., a kangaroo hopping across the screen while a portion of "Greensleeves" was played and a positive message was displayed). PC responses were reinforced with visual (unanimated) effects (e.g., a picture of a dinosaur and a positive message displayed). A NWE response resulted in the correct answer being displayed over the student's response for 2 sec, the screen blackened for 3 sec, and a repetition of the problem. A WE response resulted in the correct answer being displayed over the student's response for 2 sec, and the screen blackened for 3 sec. An NR error resulted in the correct answer being displayed for 2 sec and then the next problem being presented. At the end of each session, which resulted in 100% UC responses, an extended animated visual and auditory display was provided. Following each session, the teacher placed a check for each correct response (UC or PC) on the student's point card. Differential reinforcement of UC and PC responses was initiated during instruction if progress toward 100% UC responses was slow (i.e., differential reinforcement was begun on the eighth session following the student responding with more than 50% UC responses if one session at 100% UC responses had not been achieved). During differential reinforcement conditions, both UC and PC responses were reinforced by the computer software, but only UC responses were reinforced with a check on the point card until criterion was met.

Review procedures. In an attempt to facilitate maintenance and generalization, beginning with the class period of the first instructional session, the student was required to complete an untimed review worksheet each day he or she participated in a probe or instructional session. This sheet initially consisted of 15 randomly selected facts the student had responded to correctly during the screening session. Target facts were not initially presented on these worksheets. However, as each targeted fact set reached criterion, those problems were added to the review pool to be included on the worksheet each day. Facts were presented in a horizontal orientation, and students were required to correct any facts that had been answered incorrectly.

Generalization procedures. Several types of stimulus and response generalization were assessed: a vertical format following training in a horizontal format (written response), the reverse of the targeted fact (written response), and a verbal response to a flashcard presentation of the targeted fact. Generalization and fluency were assessed using timed pretests and posttests.

Generalization to a different format was assessed using pretest and posttest worksheets similar to those used during review. These sheets consisted of the 15 targeted fact problems presented in a vertical orientation. The student's percentages of correct responses within 75 sec (determined by allowing 5 sec for each of 15 facts) were compared to estimate orientation generalization.

Generalization to the reverse problem was assessed using pretest and posttest worksheets consisting of the reverse problem for each targeted fact. The amount of time allowed to complete the worksheet was determined by multiplying the number of reverse facts by 5 sec. Generalization to the reverse problem was estimated by comparing the percentages correct on the pretest and posttest. Problems requiring no generalization to the reverse fact (e.g., 6 × 6) were not included on this sheet. The students' responses were reinforced on a noncontingent basis with verbal praise and a check on the point card for completion of each worksheet during pretesting and posttesting.

Generalization to a verbal response was estimated by comparing results of a pretest using flashcard stimuli presented by the teacher (screening) to a posttest using the same flashcards. Students were required to read the problem aloud and state the answer, if they knew it, within 5 sec. Reinforcement consisted of verbal praise for correct responses. Incorrect responses and no responses were ignored, and the next problem was presented.

Experimental Design

The effectiveness of the constant time delay procedure and the CAI package was evaluated using single-subject research design methodology (Barlow & Hersen, 1984; Tawney & Gast, 1984). Unlike group research designs, single-subject research designs use the same subject as his or her own control. That is, each subject's behavior is evaluated under both a preintervention condition, referred to as baseline or probe, and an intervention condition. In the current investigation, a multiple-probe design (Tawney & Gast, 1984) across sets of multiplication facts and replicated across six subjects was used to evaluate the effectiveness of the computer program utilizing the constant time delay procedure. This design is similar to the multiple-baseline design in that the intervention (in this case, instruction on the multiplication facts using the constant time delay technique) is applied to one set of facts at a time; the other sets of facts remain in the probe (preintervention) condition. However, in contrast to the multiple-baseline design, baseline data are not collected continuously on the untrained behaviors but are probed intermittently. This design requires less testing time and yet provides sufficient data to evaluate experimental control.

Experimental control is demonstrated with a multiple-probe design when change in a positive direction occurs in one set of facts after the intervention is applied; the untrained sets remain at or near preintervention levels. When the intervention is applied to each of the other sets, positive change is seen in the set at that time. Improved confidence in the demonstration of experimental control results when this change in the behavior upon application of the independent variable (i.e., instruction using constant time delay) is replicated across subjects.

Reliability and Social Validity Procedures

Reliability of the computer software was evaluated prior to the beginning of the study. One student who was not included in the investigation started the program 3 weeks before the other subjects began. In this manner, program bugs were worked out prior to the initiation of the study. The teacher also observed the student as he accessed his program to be sure he had chosen the correct one. In addition, computer printouts were analyzed after each session to ensure that the correct condition had been implemented and the correct number of trials had been presented as well as to determine the condition to be implemented in the next session. Data from all probe conditions and generalization assessments were analyzed by a paraprofessional and the teacher using a point-by-point method. The number of agreements was divided by the number of agreements and disagreements and multiplied by 100.

The social validity of the instructional process (Wolf, 1978) was investigated anecdotally through individual questioning by the instructor. The five students who were present for posttesting responded to the following enquiries:

1. Do you like doing the times tables on the computer?
2. Do you think it helped you learn them?
3. Did you like it better working on the computer or with the teacher doing the flashcards (during their previous experience with constant time delay)?
4. Do you think you learned more with the teacher or the computer helping you?

RESULTS

Reliability

There were no computer malfunctions during the study. Following four sessions, students did not successfully print the performance display, but the data stored on the hard drive were used to analyze performance. During two sessions, students accessed the wrong program, but they were stopped by the teacher who assisted in opening the correct program. Reliability of the software program was 100% for presenting the correct condition and 30 trials per session, consisting of 2 trials for each fact during probe conditions and 6 trials per fact during intervention conditions. Interobserver reliability was 100% for scoring student responses.

Effectiveness

Figures 1 to 6 report the performance of students during probe and instructional sessions. UC responses are represented by triangles and PC responses by closed circles. Dashed vertical lines indicate condition modification (e.g., differential reinforcement for UC responses and reinforcement thinned to a VR–5 schedule), and scale interruptions indicate spring break and extended student absences.

On achievement of stability or a countertherapeutic trend in the probe condition, training was begun on each set of facts. Following the first session (conducted with a 0-sec delay), students evidenced an accelerating trend to criterion. This was consistent across all students and all sets of facts. The probe sessions that followed the instructional sessions showed that the skill was maintained at levels well above preinstruction probes. Retraining on facts missed during probe sessions was conducted with Charlie and Danny after the instructional sessions were completed. Bo' moved before retraining could begin. Five facts that were frequently missed during probe conditions were grouped to form a retraining set. During retraining, instruction was begun with a 5-sec delay; otherwise, instruction proceeded in the same manner as the other sets until criterion was met. Criterion for retrained sets was 100% UC responses on a CRF schedule for one session, followed by one session at 100% UC responses on a VR–5 reinforcement schedule. Then these students participated in a final probe condition. Differential reinforcement of UC responses was used following Session 11 to help Danny reach criterion.

Efficiency

Efficiency data for the six students are reported in Table 5. Although this was not a comparative study, these data provide descriptive information regarding the instructional procedures. In general, the six students reached criterion in a mean of 11.1 instructional sessions per set (range = from 8 to 15 sessions). They required a mean of 68.5 min (range = from 45 to 101 minutes) of instructional time per set. The mean percentage of errors per student was 5.3% (range = from .4% to 8%) across all sets of facts.

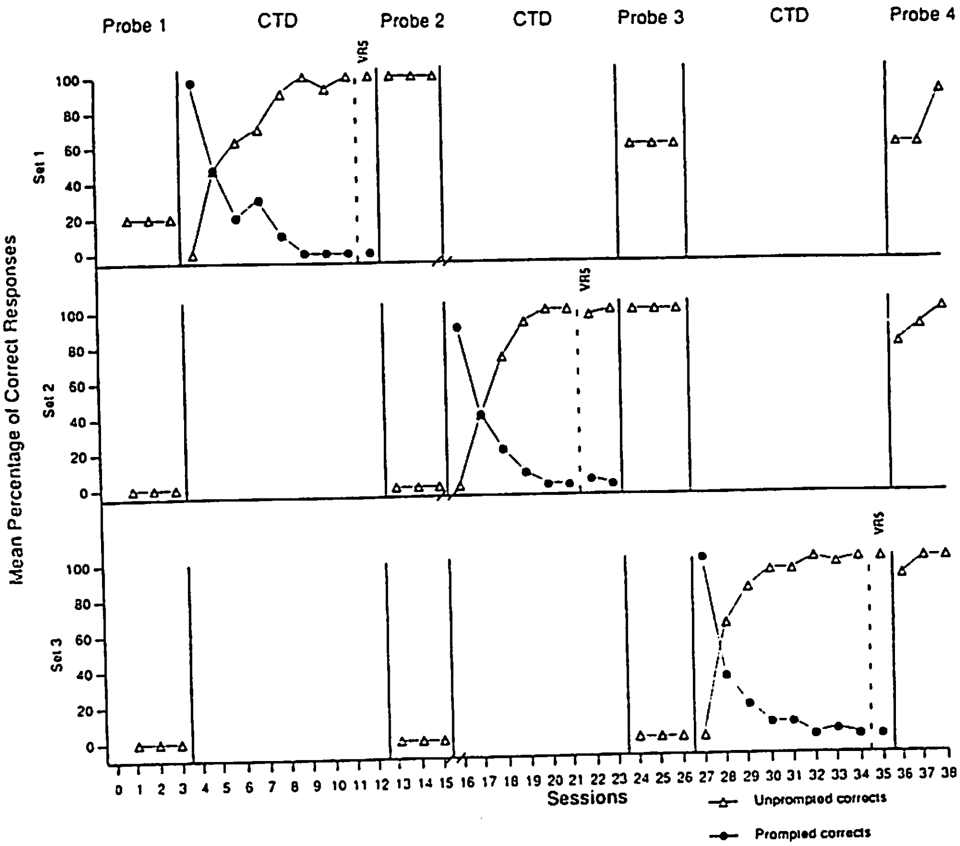

FIGURE 1 Mean percentage of correct responses for Tommy across sets of multiplication facts.

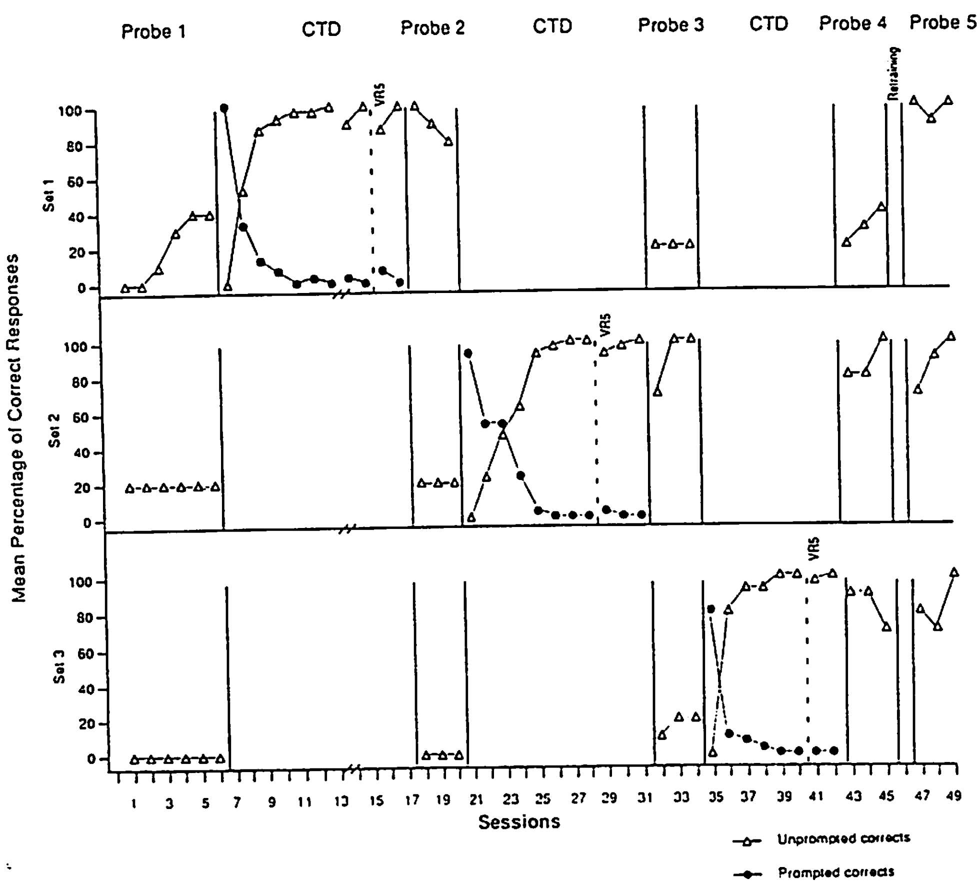

FIGURE 2 Mean percentage of correct responses for Charlie across sets of multiplication facts.

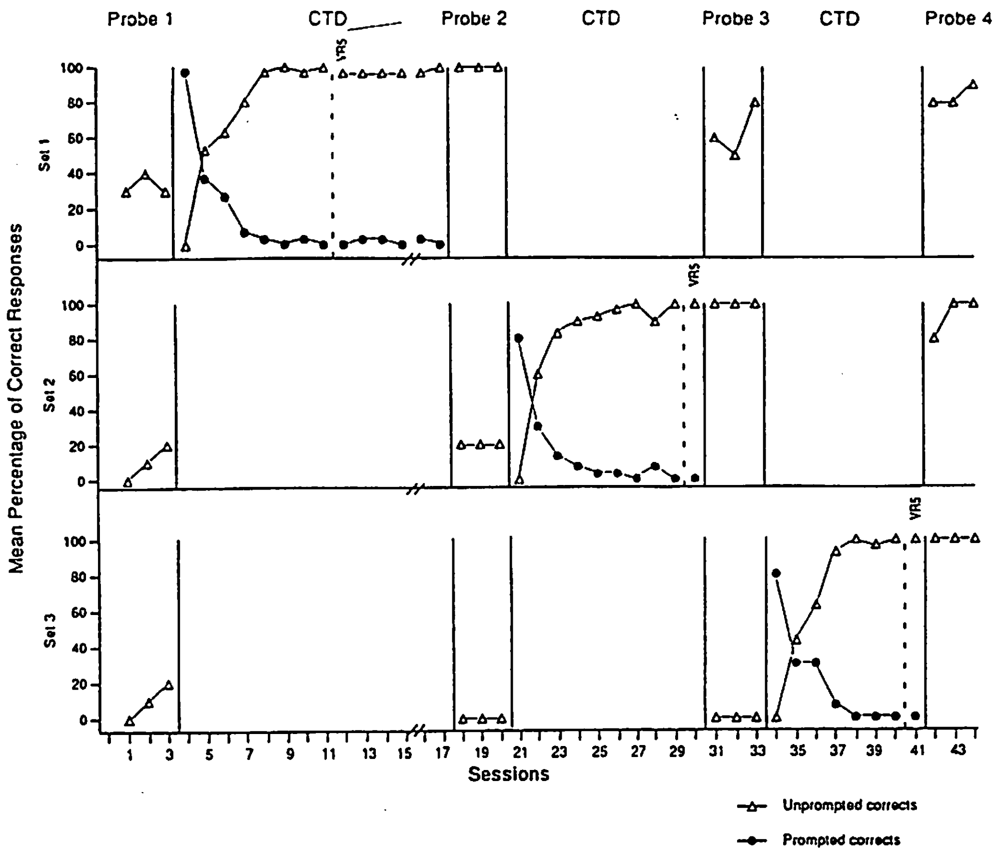

FIGURE 3 Mean percentage of correct responses for Jimmy across sets of multiplication facts.

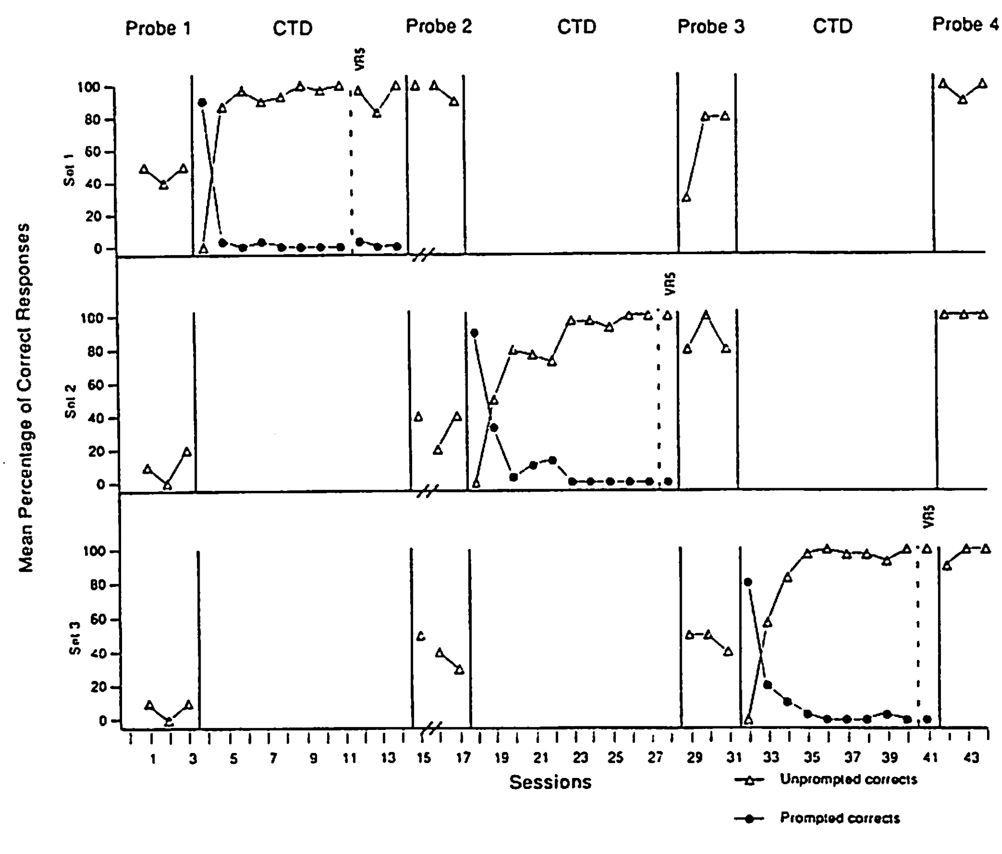

FIGURE 4 Mean percentage of correct responses for Bill across sets of multiplication facts.

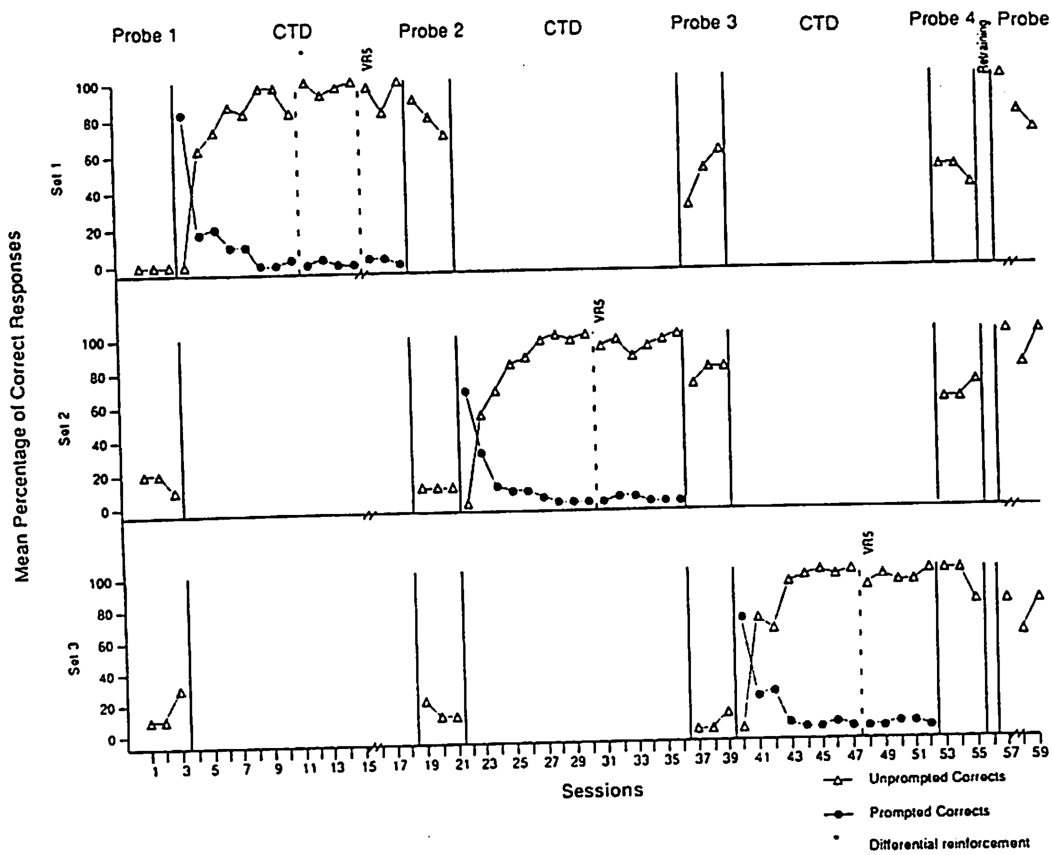

FIGURE 5 Mean percentage of correct responses for Danny across sets of multiplication facts.

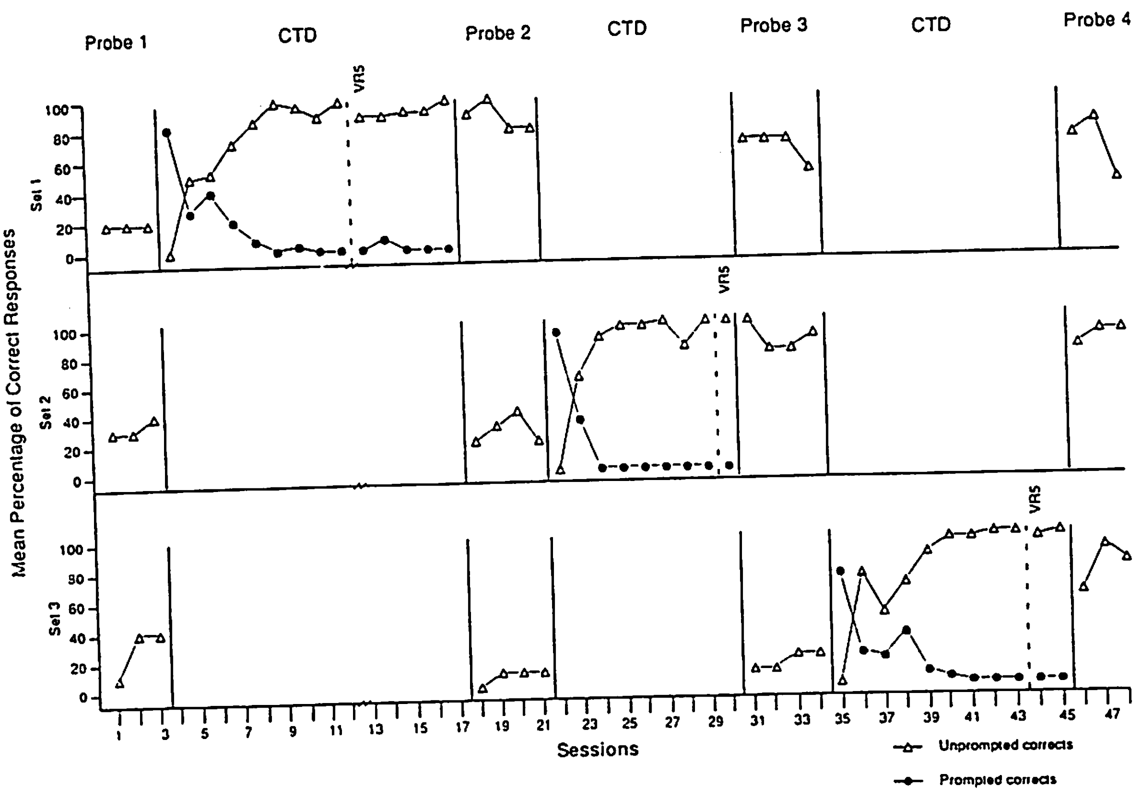

FIGURE 6 Mean percentage of correct responses for Bob across sets of multiplication facts.

TABLE 5
Efficiency Data for Trained Sets of Facts to Criterion

Subject	*No. of Errors*	*% of Errors*	*Minutes to Criterion*	*Sessions to Criterion*
Tommy				
Set 1	10	3.7	70	9
Set 2	11	3.3	64	11
Set 3	1	0.4	63	9
M	7.3	2.5	65.7	9.7
Charlie				
Set 1	9	3.0	66	8
Set 2	17	5.2	66	10
Set 3	11	4.6	45	12
M	12.3	4.3	59	10
Jimmy				
Set 1	13	3.1	84	14
Set 2	13	4.3	66	10
Set 3	17	7.1	49	8
M	14.3	4.5	66.3	10.7
Bill				
Set 1	17	5.2	68	11
Set 2	25	7.6	70	11
Set 3	18	6.0	69	10
M	20	6.3	69	10.7
Danny				
Set 1	28	6.2	101	15
Set 2	36	8.0	84	15
Set 3	24	6.2	74	13
M	29.3	6.8	86.3	14.3
Bob				
Set 1	31	6.9	84	15
Set 2	13	4.8	50	9
Set 3	25	7.6	60	11
M	23	6.6	64.7	11.7
Students 1-6 *M*/Set	17.7	5.3	68.5	11.1

Generalization

Generalization data are presented in Table 6. Posttest information is not presented for Bob, due to his withdrawal from school prior to the completion of the study. Generalization assessment from pretests and posttests indicated variable performance across students. Assessment of generalization to a different problem format indicated a range of increase from 13% to 86%. Posttests of the reverse fact indicated an increase in percentage correct for all students except Charlie (range = from 20% to 75%). Increases in percentage correct for oral responses, following a flashcard presentation of the fact problem, ranged from 53% to 100%.

TABLE 6
Generalization Data (% Correct)

	Student					
	Tommy	*Charlie*	*Jimmy*	*Bill*	*Danny*	*Bob*[a]
Orientation						
Pretest	7	20	33	33	27	47
Posttest	93	33	67	67	80	–
Increase	86	13	34	34	53	–
Reverse fact						
Pretest	17	30	36	33	42	55
Posttest	92	10	64	75	83	–
Increase	75	−20	28	42	41	–
Oral response						
Pretest	0	0	0	0	0	0
Posttest	100	53	73	100	80	–
Increase	100	53	73	100	80	–

[a]Bob moved before posttesting.

Social Validity

Results of the questionnaire investigating social validity indicated that students liked working on their times tables on the computer (100% agreement), thought it helped them learn the times tables (100% agreement), preferred to work on the computer to working with the teacher and flashcards (100% agreement for the computer), and thought they learned more with the computer (60% agreement) than with the teacher (40% agreement).

DISCUSSION

The results of this study indicate that the 5-sec constant time delay procedure incorporated into a software program developed using Authorware Professional (Authorware, Inc., 1990) was an effective method of teaching multiplication facts to students with LDs. Visual inspection of the data indicate that the six students learned all 15 targeted facts with no covariation across sets prior to instruction with that set. Probe performance prior to instruction indicates that the percentage of UC responses was stable or decelerating. On introduction of constant time delay instruction across sets and students, the percentage of UC responses steadily rose to 100%. The data also suggest that the procedure was efficient, resulting in few errors (M = 5.3% across students and sets) and on the average requiring 68.5 min (11.1 sessions) of instructional time per set. Thus, in approximately 1 hr of instructional time, these students with severe LDs memorized five multiplication facts. Thus, we may predict that in approximately 11 instructional hr students could be expected to learn all 55 of the basic multiplication facts (excluding reverses), despite possible attentional deficits, rote memory disorders, or short-term memory deficits. Considering the importance of the acquisition of the multiplication facts and the development of fluency with them, such an expenditure of instructional time seems appropriate. In addition, there was a general decelerating trend in number of minutes to criterion across sets. As the students became more familiar with the instructional procedure, they required less time to learn the facts. These results are particularly notable when the severity of the students' LDs is considered. All students had been considered disabled enough to require services via a self-contained classroom. In addition, all six students exhibited attention problems and impulsivity, and three had been diagnosed as having an attention deficit disorder.

The results of this study support the effectiveness of the constant time delay instructional method in teaching multiplication facts to students with LDs or mild intellectual handicaps (Cybriwsky & Schuster, 1990; Koscinski & Gast, in press; Mattingly & Bott, 1990). They extend previous research by demonstrating that the procedure is adaptable to auto-instruction using computer software. Although much research has been conducted on the effectiveness of CAI with special education students, the results have been equivocal (Bahr & Rieth, 1989; Iacono & Miller, 1989). Our study lends support to the position advanced by Bahr and Rieth (1989) that software design may be the determining factor in using CAI to improve academic skills with students with LDs.

The results of generalization testing indicate that generalization to different stimulus and response modes occurs with varying degrees of success for different students. As with most groups of students with LDs, this was a heterogeneous one with varying abilities, strengths, and weaknesses. Tommy and Bill were very successful at generalizing to a different orientation and to the reverse fact, as well as to oral responses. Charlie had more difficulty with these tasks. Students who have problems generalizing may need additional instruction with other stimuli and response modes to facilitate successful generalization. The teacher noted that Charlie, who had the most difficulty with all generalization tasks, was not adept at saying or writing numerals correctly. He struggled to respond correctly within the imposed time limit (e.g., "I know it! I know it! Um. . . . It's got a 2 and then a 1!"). Because Charlie learned to keyboard numerals correctly using the constant time delay procedure to learn the multiplication facts, this same procedure might be beneficial to him and other students with similar problems in situations requiring different types of numerical responses (e.g., written or oral). All students showed better generalization to a verbal response to a flashcard presentation of the problem than to the paper-and-pencil tasks. This may have been due to the similarity of that procedure to the constant time delay procedure used for instruction in the computer software. Written generalization assessments were more similar to the untimed review sheets the students were required to complete each day. Note that students tended to revert to counting strategies while working on both the review sheets and the generalization worksheets presented during posttesting. Thirty-two of the 43 errors (74%) on timed generalization posttests requiring written responses were due to a missing response rather than an incorrect response. The lack of practice with timed assessments requiring a written response may have been the primary factor in the observed discrepancy between generalization to verbal and written responses. It might be beneficial in future investigations to use timed rather than untimed review sheets for daily practice. Further investigation into the generalization process (e.g., to problem-solving applications) would also be valuable.

Although maintenance was not a specific area of investigation in this study, the results suggest that some students maintained the multiplication facts over time better than others. Charlie, Danny, and Bob had more difficulty maintaining a high percentage of UC responses in Probe 4 than the other students. Students who have difficulties retaining learned material may require more frequent review of the facts than was provided by the worksheet, for which no time limit was imposed, in this study. The results of retraining five facts frequently missed by Charlie and five frequently missed by Danny during probe conditions (Bob moved before retraining could be completed) indicate that retraining was an efficient process. This retraining required only seven instructional sessions (36 min) for Charlie and four sessions (21 min) for Danny. Future investigations may benefit by incorporating review trials or sessions into the instructional process. One possibility might be to combine Set 1 and Set 2 and instruct this combination to meet criterion prior to instruction with Set 3. Sets 1, 2, and 3 could likewise be combined and taught together before instruction with Set 4, and so forth.

In this investigation, we studied the effectiveness of an instructional package that included constant time delay, an active specific attentional response, and differential reinforcement. We did not wish to assess the relative contribution of each component of the package. Such a component analysis would be a worthwhile undertaking in a future study.

Developing the software was greatly facilitated by the use of Authorware Professional (Authorware, Inc., 1990). Primary difficulties involved the use of variables with which we were relatively unfamiliar. The manual was not of much assistance in that regard for a novice programmer. Further clarification concerning variables and functions in the documentation for Authorware Professional would be extremely valuable. At its present stage of development, the multiplication software would be very difficult for a classroom teacher to individualize for each student. In addition, the cost of Authorware Professional might be prohibitive for teachers or programmers not affiliated with a university or having other access to the program. Nevertheless, the opportunities provided by the various authoring programs for teachers and programmers to develop educationally sound programs somewhat easily are tremendous. Further research is needed to evaluate the effectiveness and efficiency of such programmed software.

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