Efficient Class-wide Remediation: Using Technology to Identify Idiosyncratic Math Facts for Additional Automaticity Drills

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Abstract

A multiple baseline design was used to evaluate the effects of a modified Detect, Practice, and Repair (DPR) procedure on multiplication-fact fluency with 10 low-achieving 5th-grade students. Experimenters modified the DPR procedure using Microsoft© PowerPoint© slide shows to conduct the assessments and allow for more rapid self-evaluation in order to identify target facts. Next, each student completed the cover, copy, and compare (CCC) practice procedures only on the problems which he/she did not answer correctly within 3 s. Results suggest that the procedure enhanced multiplication fact fluency across all 10 students. However, increasing baseline data on the third list of problems hindered interpretation of effects. The discussion focuses on improving skill remediation by using efficient procedures for creating idiosyncratic curricula.
Keywords: Technology, Efficient Remediation, Idiosyncratic Target Behavior, Math-Fact Automaticity, Class-wide Remediation

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Researchers have found evidence that many students do not master basic mathematics skills and in 2009, for the first time in two decades, national U.S. math scores at a fourth-grade level did not improve (National Center for Educational Statistics, 2009). These findings support the need for the development and evaluation of science-derived basic math skills interventions (Maccini, Mulcahy, & Wilson, 2007). Haring and Eaton (1978) developed a multi-stage hierarchy of skill development. During the initial stage, acquisition, the focus is on enhancing response accuracy. Once a skill can be performed accurately the focus shifts to developing speed of accurate responding, also known as fluency or automaticity (Deno & Mirkin, 1977; Hasselbring, Goin, & Bransford, 1988.

Several theories may explain why students who are fluent or automatic with basic addition, subtraction, multiplication, and division facts are more likely to experience success acquiring and mastering more advanced mathematics objectives (Deno & Mirkin, 1977; Haring & Eaton, 1978; Johnson & Layng, 1992; McCallum, Skinner, Turner, & Saecker, 2006; Shapiro, 2004; Skiba, Magneusson, Marston, & Erickson, 1986; Skinner, 1998). Individuals have limited cognitive capacity and automatic responding is thought to require fewer cognitive resources, including working memory and attention. Because many complex mathematics objectives require students to perform basic computations, those who expend too much of their cognitive capacity performing basic operations may have insufficient capacity to apply toward acquiring complex mathematic skills (Gagne, 1983; LaBerge & Samuels, 1974; Skinner & Schock, 1995; Woodward, 2006). Students who can complete basic math computations problems with rapidity are likely to expend less time and effort on math activities and have less math anxiety (Billington, Skinner, & Cruchon, 2004; Cates & Rhymer, 2003). Consequently, those with greater basic-fact fluency are more likely to choose to engage in math activities, which further enhance skills (Skinner, 1998; Skinner, 2002; Skinner, Pappas, & Davis, 2005).

Idiosyncratic Target Behaviors and Behavioral Consultation

Researchers have drawn an important distinction between fluency and automaticity (Skinner & Daly, in press). The term fluency reflects the ability to respond to a group of stimuli both quickly and accurately. Thus, a fluent typist can type 150 words correct per minute. However, when discussing mathematics researchers have used the term automaticity to describe a students' ability to respond to a specific fact (e.g., 6 x 7 = __) rapidly, accurately, and with minimal effort or cognitive resources (Hasselbring et al., 1987; 1988; Poncy, Skinner, & Jaspers, 2007; Poncy, Skinner, & O'Mara, 2006). Developing the ability to respond fluently to a class of basic math facts (e.g., single-digit multiplication facts) may be caused by becoming automatic with each specific fact in that class (Skinner & Daly, in press). Consequently, as students are developing fluency, it is likely that they will have developed automaticity with some math facts (e.g., 5 x 5 = 25), but not others (Poncy et al., 2006; Poncy et al., 2007).

Behavioral consultation has been used to remedy idiosyncratic academic skill deficits (e.g., Saecker, Skinner, Brown, & Roberts, 2009). When working with academic skill deficits, one of the first steps in behavioral consultation is to identify target behaviors in need of remediation (Shapiro, 2004). Skinner and Daly's (in press) conceptualization of automaticity versus fluency makes it apparent that each student is likely to have different math facts which require targeted remediation (i.e., in need of automaticity building). Additionally, within each student, as automaticity develops with some facts, the curricula should be altered so that the student is not wasting valuable instructional/learning time on facts that he/she has already developed to the point of automaticity (Cates et al., 2003; Nist & Joseph, 2008; Poncy et al., 2006; Skinner, 2008).

Because practice enhances speed of accurate responding, interventions that occasion higher rates of accurate responding are likely to cause greater increases in automaticity and/or fluency (Codding, Chan-Iannetta, Palmer, & Lukito, 2009; Skinner, 1998; Skinner, Belfiore, Mace, Williams, & Johns, 1997; Skinner, Bamberg, Smith, & Powell, 1993; Skinner, Belfiore, & Watson, 1995; Skinner, Fletcher, & Hennington, 1996; Skinner & Shapiro, 1989). However, high rates of responding will only enhance skills when those responses are accurate (Skinner, 1998; 2010). When students are responding at high rates, immediate feedback can decrease the probability of students repeatedly practicing inaccurate responses (Skinner & Smith, 1992). Procedures are needed to reduce, as opposed to enhance time spent on mastered facts to allow student more time to practice facts which are not automated (Cates et al., 2003; Joseph & Nist, 2006; Nist & Joseph, 2008; Poncy et al., 2006; Skinner, 2008).

Detect, Practice, Repair

Detect, Practice, Repair (DPR) is a multi-component, class-wide procedure that focuses on enhancing fluency by allowing students to practice those math facts that they have not developed to the point of automaticity (Poncy et al. 2006). During a detect phase, Poncy et al. used a metronome to pace a group of students through a series of math facts, with the metronome signaling 1.5 s intervals to respond to each fact. After this paced assessment, each student circled those problems that he/she did not answer and then applied the practice phase to those identified problems by performing the Cover, Copy, Compare (CCC) procedure. CCC is a self-paced practice procedure designed to occasion high rates of active, accurate, academic responding (Skinner, Belfiore et al., 1997; Skinner, McLaughlin, & Logan, 1997; Skinner, Turco, Beatty, & Rasavage, 1989). CCC takes the learner through 5 steps: (a) the student will review the target mathematic problem, (b) study the mathematic problem with the answer, (c) cover the problem and answer, (d) write the problem and answer, (e) uncover the original problem and answer and compare their response to the original printed problem and answer.

Poncy et al. (2006) first used DPR to increase subtraction-fact fluency in 14 low-performing 3rd-grade students who were receiving special education services. Poncy et al. found that the DPR procedure yielded increases of 3.2 digits correct per week, compared to the district-wide average of .5 digits correct improvement. A subsequent application of DPR enhanced division-fact fluency in middle school students (Axtell, McCallum, Bell, & Poncy, 2009).

The Current Study

The current study was initiated by an elementary school principal and a 5-grade teacher who requested consultation designed to address math-fact deficits in a low performing class. The school had four 5th-grade math classes and this teacher taught the students who were experiencing the most problem developing math skills. Specifically, the teacher requested that the consultant develop and help implement an efficient procedure designed to enhance multiplication-fact fluency that could be applied class wide. The teacher indicated that some students had stronger multiplication skills than others, but many could not respond rapidly and accurately to all the basic multiplication facts. As DPR was designed for group application, but still allowed each student to practice only problems which each individual needed to practice, the consultant used previous DPR research (Poncy et al., 2006; Axtell et al., 2009) to guide intervention development. During the problem solving process, the consultant and educator also addressed several limitations associated with DPR.

The metronome-paced detect phase of DPR students allowed some students to work ahead or continue at their own pace, ignoring the metronome (Poncy et al., 2006). To address this concern the Microsoft© PowerPoint© program was used to present one problem every 3 s. Also, in the first study when students evaluate responses they did not consider accuracy; rather they practiced problems that they did not answer within the 1.5 s timeframe (Poncy et al., 2006). Axtell et al. (2009) addressed this by having students check their work using a printed answer board that had to be reconstructed for each trial. In the current study, immediately after students finished these paced trials, a PowerPoint© slide displayed the problems and correct answers in the same order that they were presented. This allowed each student to efficiently self-evaluate response accuracy.

Methods

Participants and Setting

The current consultation case was conducted in an urban school district in the Southeastern United States. All procedures were run within the participants regularly scheduled math classroom that contained a computer connected to a Smart Board used to project PowerPoint© slide shows. Over 90% of the students in this elementary school were eligible for free or reduced-cost meals. The 10 students (7 African American, 3 Caucasian) who participated made up the entire, intact math section. None of the students (4 female, 6 male) received special education services for mathematics. Based on Deno and Mirkin's (1977) criteria, baseline data showed that 2 students had mastered basic multiplication facts, 6 were at instructional level, and 4 were at a frustrational level. As the intervention was designed to allow students to only address facts in need of additional practice, the teacher decided that the two students who appeared to have mastered the basic facts should remain in the study.

Materials

A personal computer with Microsoft© PowerPoint© software, a projector, and a stopwatch were used for this study. Three sets (sets A, B, and C) of 12, 1-digit by 1-digit (factors 2-9), multiplication problems were created for the current study. Poncy et al. (2006) and McCallum et al. (2006) used similar multiplication sets. Three 15-slide PowerPoint slide shows were constructed for each set of problems. Each slide show began with a title slide indicating the problem set (A, B, or C). This was followed by 12 numbered slides, each containing 1 of the 12 multiplication problems. The slide show was constructed so that each problem (slide) appeared for 3 s. The next slide contained the answer-key slide for the 12 previous problems. This slide contained the problems and answers in the same order in which they were just presented. The final slide contained an overview of how to perform the CCC procedure. The slide show was constructed so that the title slide appeared first and then the slide show could be started with each of the next 12 slides appearing on a scheduled delay of 3 s. The answer-key slide (14th slide) remained displayed until the experimenter changed slides to the final (15th) slide, which provided an overview of CCC procedures.

Experimenters also constructed assessment and DRP sheets that were used for this study. For each set of problems the experimenter developed 9 assessment sheets. Each assessment sheet contained four columns, and each column contained the 12 problems from the set in random order. Experimenters also constructed DRP sheets. Each sheet contained 4 columns of 12 response prompts. In the first column were 12 numbered lines for students to write their answers during the detect phase. The next 3 columns contained 12 boxes for students to write problems and answers during the CCC phase (see Appendix).

General Procedures

Behavioral consultation. During a problem identification interview the teacher indicated that all of his 10 students needed to develop automaticity with their multiplication facts. The consultant used baseline assessment probes to validate the problem. Although these probes showed that 2 students had mastered basic multiplication facts the teacher asked that they remain in the study. Next, the consultant reviewed the relevant literature and shared it with the teacher as they developed the remediation procedure. As it would have been impractical and poor educational practice to target all multiplication facts simultaneously (McCleary et al., in press), facts were divided into three sets and each set targeted in a staggered format. Consequently, the consultant applied a multiple baseline across behaviors (problem sets) design to evaluate the effects of the interventions.

Assessment procedures.

Group administered assessment probes were used to validate the problem, gather baseline data, and evaluate intervention effects across the three sets of problems. During each assessment session, students digits correct per minute (DC/M) were assessed on each set of problems (Sets A, B, and C). During each assessment session students were given 30 s to complete as many problems as they could on each sheet. Across sessions the sets were assessed in random order. Also 3 different assessment sheets were constructed for each problem set and these sheets were applied in sequential order across sessions.

After students were seated, sheets were placed upside down on each student's desk. The group was instructed to work problems in order as rapidly and accurately as possible. Additionally, they were told to avoid spending too much time on any problem by skipping problems that they could not answer. After being notified, the experimenter started a stopwatch and after 30 s had elapsed the students were instructed to stop and assessment sheets were collected. Identical procedures were then applied to the next two probes. When the intervention phase began identical procedures were applied immediately after the group finished the detect and CCC procedures.

Assessments were scored using Deno and Mirkin's (1977) method for measuring DC/M. Specifically, a digit was scored as correct if the correct digit was written in the correct place. For example, consider the problem 4 x 3 = ___. A response of 14, 22, or 2 would be scored as 1 digit correct and a response of 12 would be scored as 2 digits correct. As students were given 30 s to complete problems, these data were converted to DC/M by multiplying digits correct by 2.

Intervention procedures. During the intervention phase, students worked at their assigned desk. After intervention sheets were distributed, students were told that math fact problems would appear on the screen and that they were to attempt to write the correct answer on their sheet before a new problem was displayed. Students were told to pay careful attention and work rapidly. The 12 problems were then display for 3 s each. Immediately after the 36-s slide show was finished, the answer key was displayed which contained the problems and answers in the same order as the slide show.

The students were asked to evaluate their work, identifying the first five problems that they did not answer correctly. Next they wrote these problems and answers in the second column of their CCC sheet. Finally, the experimenter switched to the final slide which described CCC procedures and students completed the CCC procedure with the five inaccurate problems. Students were trained to perform the CCC procedure on the first session. Using a demonstration, the experimenter illustrated how to perform the CCC procedure. To begin the experimenter looked at the first problem and answer, covered it, and then wrote the problem and answer in the adjacent column. Next, the experimenter evaluated the response and when correct moved to the next problem and answer; but when incorrect the experimenter taught the students to repeat the CCC procedure again with the final column. After demonstrating and describing both accurate and inaccurate CCC procedures the students were instructed to complete the CCC procedure with their five problems. Throughout the experiment the consultant and teacher monitored the students as they performed the self-evaluation and CCC procedures and prompted them to correct procedural errors (e.g., peaking during CCC).

Modifying the procedures. During the last phase, when Set C problems were targeted, two students began to complete the 30-s probes by rapidly writing down random numbers, without regard for accuracy. Therefore, a loose rewards program (e.g., no clear criteria) was added. Specifically, before the DRP session targeting set C the students were told that they could earn mechanical pencils if they tried their best and improved their response accuracy and speed. All 10 students were given mechanical pencils on the two sessions, regardless of their DC/M scores.

Interscorer Agreement

All of the assessments were initially scored by the primary researcher. To obtain interscorer agreement an independent researcher, not linked to the consultation case, scored 12 sets (22%) of the assessment sheets. Interscorer agreement was calculated by dividing the number of actual agreements on digits correct by the number of possible agreements on digits correct and multiplying by 100. Interscorer agreement for the probes was 94.4%.

Results

Figure 1 shows the class average DC/M scores across phases and sets of problems. Across all three problem sets the class showed an increasing baseline trend. For Sets A and B, increasing baseline trends stabilized at approximately 28 - 30 DC/M. Immediately after the intervention was applied to Sets A and B students showed an increase in DC/M. The immediate increase was largest for Set B, but a steadily increasing trend during the intervention phase on Set A problems also provided strong evidence of a treatment effect.

Figure 1 shows an increasing baseline trend in DC/M on Set C problems. This increasing baseline trend may have been caused by practice effects occasioned by the daily assessment or spillover effects (e.g., learning Set A and B problems enhance fluency with Set C problems, see McCleary et al., in press). Additionally, initial baseline performance was lowest on Set C; thus, regression to the mean may have influenced this trend. This increasing baseline trend hinders our ability to draw strong cause-and-effect conclusions and may have made it difficult to find an immediate increase after the intervention was applied to these problems.

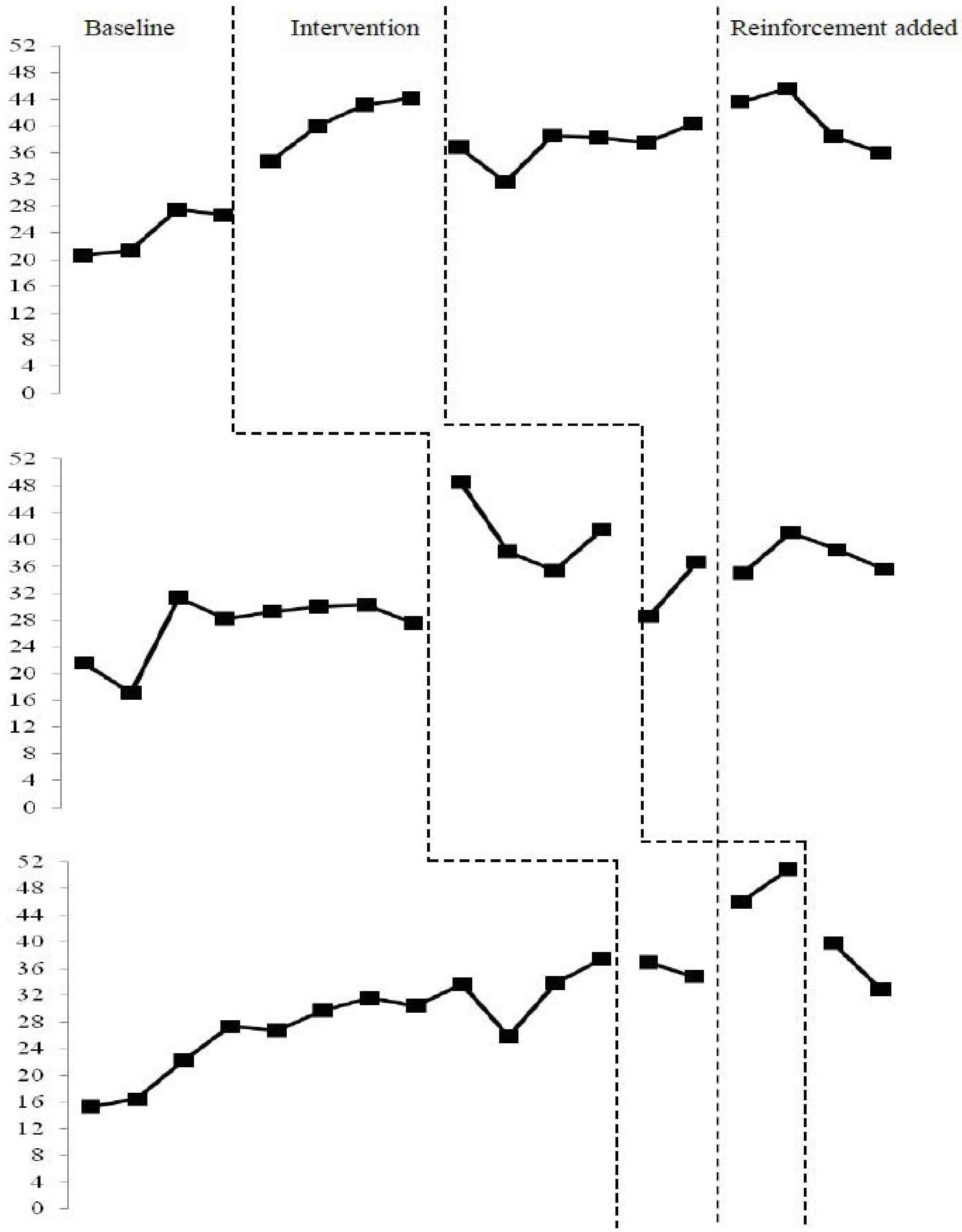

Fig. 1 Multiple Baseline Digits Correct Per Min.

As Set C problems were the last targeted, students may have lost interest in some aspects of the DPR procedure. In fact, within the first two Set C sessions, two students began writing down answers as rapidly as possible, without regard for accuracy during assessments. Consequently, after the second Set C session, researchers supplemented the procedures with a loosely applied reward program where all students where told that they could earn mechanical pencils contingent upon improvements on assessments (see McCleary et al., in press and/or Saecker et al., 2009). After this reward program was applied students performance increased.

Table 1 shows the class average and each students' mean DC/M across sets and phases along with letters indicating whether their fluency scores placed them at frustrational (F, 0 - 19 DC/M), instructional (I, 20 - 39 DC/M), or mastery (M, 40 or more DC/M) levels based on Deno and Mirkin's (1977) criteria. Across the three problem sets, students mean intervention scores were 13.2 - 21.2 DC/M higher than mean baseline scores. With respect to individual's average performance, with the exception of Student 5's performance on Set A, each showed increases from baseline to treatment phases across all problem sets.

Only two students (5 and 7) were considered to be at mastery level during baseline data collection. Across all three lists these students showed an average increase of 25.2 DC/M from baseline to interventions (range = -2.9 - 51.1). These results suggest that the intervention may have enhanced the students who already mastered basic facts. Two students' (1 and 2) average baseline scores ranged from 19 - 39 DC/M, placing them at Deno and Mirkin's (1977) instructional level. These students average improvement was 20.28 (range = 3.7 - 34.7). Baseline performance suggested that the other six students were at frustration level with basic multiplication facts. Table 1 shows that students 3, 4, 6, 8, 9, and 10 increased their average performance from baseline to intervention phase (M = 9.46, range 5.6 - 19.9) with all six students showing improvement across each of the six lists.

Table 1. Digits correct

	Set A		Set B		Set C		Total Change	
Student	DC/M BL	DC/M INT	DC/M BL	DC/M INT	DC/M BL	DC/M INT	DC/M BL	DC/M INT
1	24.3 (I)	59 (M)	23.2 (I)	49. 5 (M)	16.5 (F)	46 (M)	21.3 (I)	51.5 (M)
2	17.5 (F)	37 (I)	24.6 (I)	28.3 (I)	20 (I)	28 (I)	20.7 (I)	31.1 (I)
3	8.6 (F)	12 (F)	2.6 (F)	9 (F)	4 (F)	11 (F)	5 (F)	10.6 (F)
4	24 (I)	30 (I)	19.5 (I)	29.8 (I)	12.5 (F)	21 (I)	18.6 (F)	26.9 (I)
5	50 (M)	47.1 (M)	58 (M)	82 (M)	48 (M)	78.5 (M)	52 (M)	69.2 (M)
6	12.5 (F)	31.9 (I)	22.4 (I)	24.5 (I)	21.5 (I)	33 (I)	18.8 (I)	29.8 (I)
7	54 (M)	66 (M)	33.4 (I)	70 (M)	43.5 (M)	94.6 (M)	43.6 (M)	76.8 (M)
8	16 (F)	27 (I)	19 (F)	31.5 (I)	13.5 (F)	29 (I)	16.1 (F)	29.1 (I)
9	17.3 (F)	32 (I)	18.6 (F)	38 (I)	18 (F)	43.5 (M)	17.9 (F)	37.8 ()
10	15.3 (F)	40 (I)	8.6 (F)	10 (F)	12.6 (F)	37.5 (I)	12.1 (F)	29.1 (I)
Mean	23.9 (I)	38.2 (I)	23 (I)	37.2 (I)	21 (I)	42.2 (M)	21 (I)	42.2 (M)

Discussion

Previous researchers have found evidence that DPR can be used to enhance math-fact fluency in classrooms (Axtell et al., 2006; Poncy et al., 2006). In the current consultation case, we modified DRP procedures by incorporating technology (PowerPoint©) to enhance the quality and efficiency of the procedures. Although the increasing baseline trend on Set C problems prevents us from drawing strong cause-and-effect conclusions, the current results support the use of these procedures for building class-wide multiplication fluency, as all 10 students showed individual gains from their baseline averages to the intervention stage across sets A, B, and C.
We modified previous DPR procedures by using computer-based technology to assist with the detect phase, allowing each student to target idiosyncratic math facts during CCC. The PowerPoint© slide shows appeared to work well. Relative to metronome-paced worksheets, the PowerPoint© slide shows prevented students from working ahead (they could not see the next problem); although, they could continue working after a problem was removed from the screen. Additionally, the rapidly-paced (3 s per slide) program appeared to capture and maintain student attention. Unfortunately, the same cannot be said for the 30-s assessment procedures as at least two students eventually stopped trying to write the correct answers during some sessions. The data suggests that the consultant successfully addressed this problem by announcing and implemented rewards continent upon quality work. Therefore, future researchers should determine if adding immediate feedback and/or reward components to these procedures enhances learning rates.

Another limitation of the current study was inconsistent effects across and within students. Although the sample size of students at each level (i.e., frustrational, instructional, and mastery levels) was small, the intervention appeared to be less effective for those at the instructional level. With respect to individuals, students 2 and 9 had similar mean DC/M during baseline; however, student 9 made much larger gains following the application of the intervention. Student 2's data provide a good example of within-subject treatment effect variability. Student 2 initially improved 19.5 DC/M on Set A, but his improvement was only 3.7 and 8 DC/M on Sets B and C respectively. Future researchers should attempt to identify factors that account for this within and across subject and group variability. Perhaps offering feedback and rewards may reduce this variability by eliciting more consistent effort from students and less variable effects within and across students

Summary

When working with educators on academic skills, consultants are often asked to address deficits class wide or in group formats (Hawkins, in press). Since basic academic skills are often needed to learn and master more advanced skills, the goal should be to remedy these deficits as quickly as possible so that students can experience more success on current and future academic objectives (Skinner, 2008; 2010). When faced with groups of students (e.g., an entire class) in need of remedial service, specific targets often vary across students. Within students, remediation targets change as students develop their skills. The current paper describes a technology-based group procedure that allows educators to target idiosyncratic math facts in a class-wide format. Future applied research should continue to develop and evaluate group procedures that allow educators to efficiently remedy skill deficits by applying instructional time only to target behaviors in need of remediation (Cates et al., 2003; Poncy et al., 2006; Nist & Joseph, 2008; Skinner, 2008; 2010; Skinner & Schock, 1995).

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Appendix: DRP Sheet

1. ____________			
2. ____________			
3. ____________			
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9. ____________			

10. ____________

11. ____________

12. ____________
