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ANALYSIS OF PRECURRENT SKILLS IN SOLVING MATHEMATICS STORY PROBLEMS

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We conducted an analysis of precurrent skills (responses that increase the effectiveness of a subsequent or "current" behavior in obtaining a reinforcer) to facilitate the solution of arithmetic word (story) problems. Two students with developmental disabilities were taught four precurrent responses (identifying the initial value, change value, operation, and resulting value) in a sequential manner. Results of a multiple baseline design across behaviors showed that the teaching procedures were effective in increasing correct performance of each of the precurrent behaviors with untaught problems during probes and that once the precurrent behaviors were established, the number of correct problem solutions increased.

DESCRIPTORS: precurrent behavior, problem solving, mathematics, story problems, developmental disabilities

The principal goal of mathematics instruction is to teach students to solve practical problems (National Council of Teachers of Mathematics, 1989, 2000). Toward that end, teachers often present tasks to students in the form of word (story) problems to illustrate a wide range of everyday activities (e.g., cooking, shopping, budgeting, time management) that require competence in basic mathematics skills. Nevertheless, large numbers of students of all ages fail to demonstrate grade-level proficiency in solving story problems (Cawley, Parmar, Foley, Salmon, & Roy, 2001; National Assessment of Educational Progress, 1992). Students with disabilities have performed particularly poorly on these tasks, which are important to achieving goals of successful employment, independent living, and successful integration into school and community settings (Butler, Miller, Lee, & Pierce, 2001).

Solving story problems is often difficult because it requires both reading comprehension and mathematics skills as well as the ability to transform words and numbers into the appropriate operations. Research suggests that difficulties in discriminating the correct operation, the order of operation (when placement of the unknown within the problem differs), and extraneous informa-

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tion, as well as problems with computational speed, are factors commonly associated with poor performance in solving story problems (Zentall & Ferkis, 1993). Most behavioral research on mathematics instruction for students with disabilities has emphasized basic foundation skills (e.g., counting, number recognition, matching number words and numerals, concepts of quantity) and mathematics facts (accuracy and fluency in computation) that are necessary but insufficient for higher level problem solving (e.g., Harper, Mallette, Maheady, Bentley, & Moore, 1995; Horton, Lovitt, & White, 1992; Lin, Podell, & Tournaki-Reid, 1994; Mattingly & Bott, 1990; Miller, Hall, & Heward, 1995; Whalen, Schuster, & Hemmeter, 1996; Wood, Frank, & Wacker, 1998; Young, Baker, & Martin, 1990). By contrast, relatively few experimental investigations have examined procedures for teaching story-problem solving, especially to students with moderate to severe disabilities.

A common instructional strategy involves the use of manipulatives, in which a student uses objects (e.g., blocks) to represent parts of the problem-solving equation and then adopts a "counting all" strategy for addition problems and a "separating from" or "matching" strategy for subtraction problems, depending on whether the operation involves a change, comparison, or combination. Although manipulatives have been shown to enhance performance on story-problem tasks (e.g., Marsh & Cooke, 1996), they are limited aids because they do not ensure discrimination of the appropriate strategy for solving a particular type of problem, and are not readily applied to problems involving either large quantities or abstract concepts such as distance or time.

Several investigators have used cue cards or checklists outlining problem-solving steps to teach students with mild disabilities to solve addition and subtraction story problems. For example, Cassel and Reid (1996) taught students to use a cue card with the mnemonics FAST DRAW (corresponding to the steps of finding and highlighting the question, asking what the parts of the problem are and what information is given, setting up the equation, tying down the sign of using addition or subtraction, discovering the sign, reading the number problem, answering the number problem, and writing the answer), which were then translated into a checklist, to solve story problems. Results showed that students' ability to generate correct equations for story problems improved following training. The effects of the procedure on correct solutions, however, were not clearly demonstrated, and prompting use of a strategy does not ensure discrimination of the relevant concepts and operations necessary to solve a problem.

Another approach involves teaching students to translate problems into equations whose components are inserted into parts of a diagram. Diagrams have been used to supplement explicit teaching of steps of a problem-solving chain in the context of computer programs (Jaspers & van Lieshout, 1994) or direct instruction (e.g., Jitendra & Hoff, 1996). Jaspers and van Lieshout, for example, compared text analysis, external modeling, a combination of the two procedures, and a control (practice) procedure on the ability of students classified as educable mentally retarded to solve story problems. Text analysis involved a four-step procedure consisting of reading the problem, determining the question being asked, locating the relevant sets, and producing the numerical answer. External modeling involved a five-step procedure consisting of reading the problem, representing the first set with squares, locating the second set on the computer screen, representing the second set with squares, and locating the answer set on the screen. Results showed that students in the external-modeling group performed better than those in the other three groups when they were allowed to use diagrams to represent the word problems, but that the text-analysis group performed better on paper-and-pencil tests. Using a similar approach, Jitendra and Hoff taught students via direct instruction to use diagrams to transform story problems into equation form. This procedure was effective in teaching 3 students with learning disabilities to solve simple addition and subtraction story problems when they were provided with a cue card stating the steps to solve the problems.

From a behavior-analytic perspective, problem solving involves a precurrent operant contingency, which functions "mainly to make subsequent behavior more effective," whereas a current operant may be characterized as the solution ("effective behavior . . . a response which is likely to be reinforced") that is made more probable by the precurrent contingencies (Skinner, 1968, pp. 120, 124). Precurrent behaviors may need to be taught, but once they are established, they can be maintained by their ultimate effect on the current behavior that directly produces the reinforcer (Skinner, 1968). Parsons (1976), for example, examined the effects of precurrent behaviors on the solution of quantity-matching problems (circling a subset of comparison stimuli equal to the number of symbols comprising the sample) by 5 preschool children. The precurrent behaviors consisted of overtly counting and marking the symbols as they were vocally enumerated. Results showed that before precurrent behaviors were taught and when they were prohibited, continuous differential reinforcement of the current behavior (terminal solutions) failed to produce accurate problem solving. Once established and when allowed to occur, precurrent behaviors resulted in accurate current behavior (problem solution), and both precurrent and current behaviors were maintained when reinforcement was contingent only on the latter.

Analysis of precurrent behaviors has implications for students who have difficulty with story problems. First, as illustrated by Parsons (1976), effective precurrent behaviors may not develop when instruction focuses only on the completion of a complex sequence of responses. As Skinner (1968) pointed out, differential reinforcement of solutions alone without access to the variables that control them "does not teach; it simply selects those who learn without being taught" (pp. 118–119). Second, instruction on aspects of a problem might occasion behaviors that are irrelevant to, or that fail to control, problem solution. Thus, cognitive strategies such as those that prompt "self-reflection" in the form of "What did you notice about how you did your work?" (Naglieri & Gottling, 1995) or instructions to "read, paraphrase, visualize, hypothesize, estimate, compute, and check" (Montague, 1992) may not be effective with students who lack precurrent skills that relate directly to problem solution. Third, mastery of component precurrent behaviors, albeit necessary, is not always sufficient for problem solving (Mayfield & Chase, 2002). In addition to learning how to apply a mathematical operation such as addition and subtraction, for example, students must also discriminate when to apply it to different problems. Finally, precurrent responses that are covert may be too weak to occasion the solution behavior (Skinner, 1957) and, because they are unobservable, are not available for correction if faulty. It is not surprising, therefore, that teacher knowledge of individual problem-solving skills was found to be a strong predictor of math achievement, and that teachers who lacked such information were more likely to rely simply on checking and monitoring student work (Peterson, Carpenter, & Fennema, 1989).

In the present study, we examined the effects of teaching overt precurrent behaviors (identifying the initial value, change value, operation, and ending value) on the current operant of solving mathematics story problems with 2 students with developmental disabilities. The precurrent behaviors were designed to facilitate problem solving when the components were arranged in varying sequences within the story problems, when the operation consisted of either addition or subtraction, and when the unknown value was in different positions in the resulting equations.

METHOD

Participants and Setting

Two individuals enrolled in an educational program for students with developmental disabilities participated. Saul and Lucien were 19 and 23 years old and had IQs of 46 and 72, respectively, as measured by the Wechsler Adult Intelligence Scale. Prerequisite skills for inclusion in the study consisted of the ability (a) to compute addition and subtraction numeric equations in which the sums were 10 or less and with the unknown in any position (e.g., $2 + 6 = ?$, $? - 4 = 3$), and (b) to read the vocabulary words used in the word problems (second-grade level). These skills were assessed informally (math achievement scores were unavailable). All training and testing sessions were conducted individually in a classroom.

Stimulus Materials

The general equations $A + B = C$ or $A - B = C$ were used to generate word problems indicating whether an individual gave away or received objects. One of the variables (A, B, or C) was unknown, and the task was to solve for the unknown. All problems represented variations of six specific equations generated by changing the operation to be performed and the location of the unknown variable. Each of the equations also was presented in two different sequences, yielding a total of 12 problem sequences. The rationale for using these different sequences was based on the assumption that generative skill acquisition would be enhanced through exposure to a variety of problem formats. A list of the equations and word sequences is presented in Table 1.

Testing and training materials consisted of a series of worksheets, each containing five different word problems drawn from the 12 basic sequences. The problems involved addition and subtraction in which the sums were 10 or less. Words used in the problems were drawn from 10 proper names, 20 verbs, and 20 object nouns. These problem sequences, numeric values, and words were combined in different ways to formulate a sufficiently large pool of problems such that neither student was exposed to the same problem more than once during the study. An example of a typical worksheet is shown in Figure 1 (formulas are shown for illustrative purposes and were not included on the worksheet).

Each problem was divided into five component parts. The initial set (1) was determined by words indicating the number of objects in the person's possession at the outset. Verbs stating which objects were either added or subtracted specified the change set (2), and these same verbs indicated the operation (3) to be performed. A phrase denoting the final number of objects in the person's possession was the resulting set (4). One set (initial, change, or resulting) was unknown and provided the question of the problem. The answer to that question formed the solution (5). Given the word problem, "If Sam began with 7 pens and ended up with 5 pens, how many did he give away?" as an example, the various components were as follows:

Initial set: Sam began with 7 pens.
Change set: How many did he give away?
Operation: Give away (subtraction).
Resulting set: Ended up with 5 pens.

Table 1
Equations and Sequences Used to Generate Word Problems

Equation	Sample word sequence
A + B = ?	1. If (name) started out with A objects and was given B objects, how many did he or she end up with? (A + B = ?)
	2. How many objects did (name) end up with if he or she started out with A objects and was given B objects? (? = A + B)
A − B = ?	3. If (name) started out with A objects and gave away B objects, how many did he or she end up with? (A − B = ?)
	4. How many objects did (name) end up with if he or she started out with A objects and gave away B objects? (? = A − B)
A + ? = C	5. If (name) started out with A objects and ended up with C objects, how many was he or she given? (A + ? = C)
	6. How many objects was (name) given if he or she started out with A objects and ended up with C objects? (C = A + ?)
A − ? = C	7. If (name) started out with A objects and ended up with C objects, how many did he or she give away? (A − ? = C)
	8. How many objects did (name) give away if he or she started out with A objects and ended up with C objects? (C = A − ?)
? + B = C	9. If (name) was given B objects and ended up with C objects, how many objects did he or she start out with? (? + B = C)
	10. How many objects did (name) start out with if he or she was given B objects and ended up with C objects? (C = ? + B)
? − B = C	11. If (name) gave away B objects and ended up with C objects, how many objects did he or she start out with? (? − B = C)
	12. How many objects did (name) start out with if he or she gave away B objects and ended up with C objects? (C = ? − B)

Solution (unknown): How many did he give away?

Experimental Design

A multiple baseline across behaviors design (Baer, Wolf, & Risley, 1968) was used to evaluate the effects of training on students' problem-solving skills. Following the collection of baseline probe data on each of the five component skills (initial set, change set, operation, resulting set, solution), training was begun on the first component and proceeded as necessary across the other four.

Procedure

Probe sessions. Probes were administered during baseline and following the completion of training on each of the separate precurrent problem-solving components. A probe consisted of 10 word problems (two worksheets). The student was requested to "Read each problem aloud. Find the answers and put your work here [as the trainer pointed to the boxes and circles]." Correct responses were defined as having the correct numbers in the appropriate boxes for known quantities, an X above the appropriate box for the unknown, the correct operation symbol in the circle, and the correct solution in the box for the unknown. Other responses (or no responses) were considered incorrect. Students were allowed 20 min to complete each probe, during which intermittent praise was delivered for on-task behavior independent of the occurrence of precurrent or current behaviors.

Training. Following the completion of baseline probes, students were taught to identify the five components of a word problem in the sequence described previously. The prompts and definitions of correct and incorrect responses for each of the five components are described in Table 2. Training on each component was preceded by a dem-

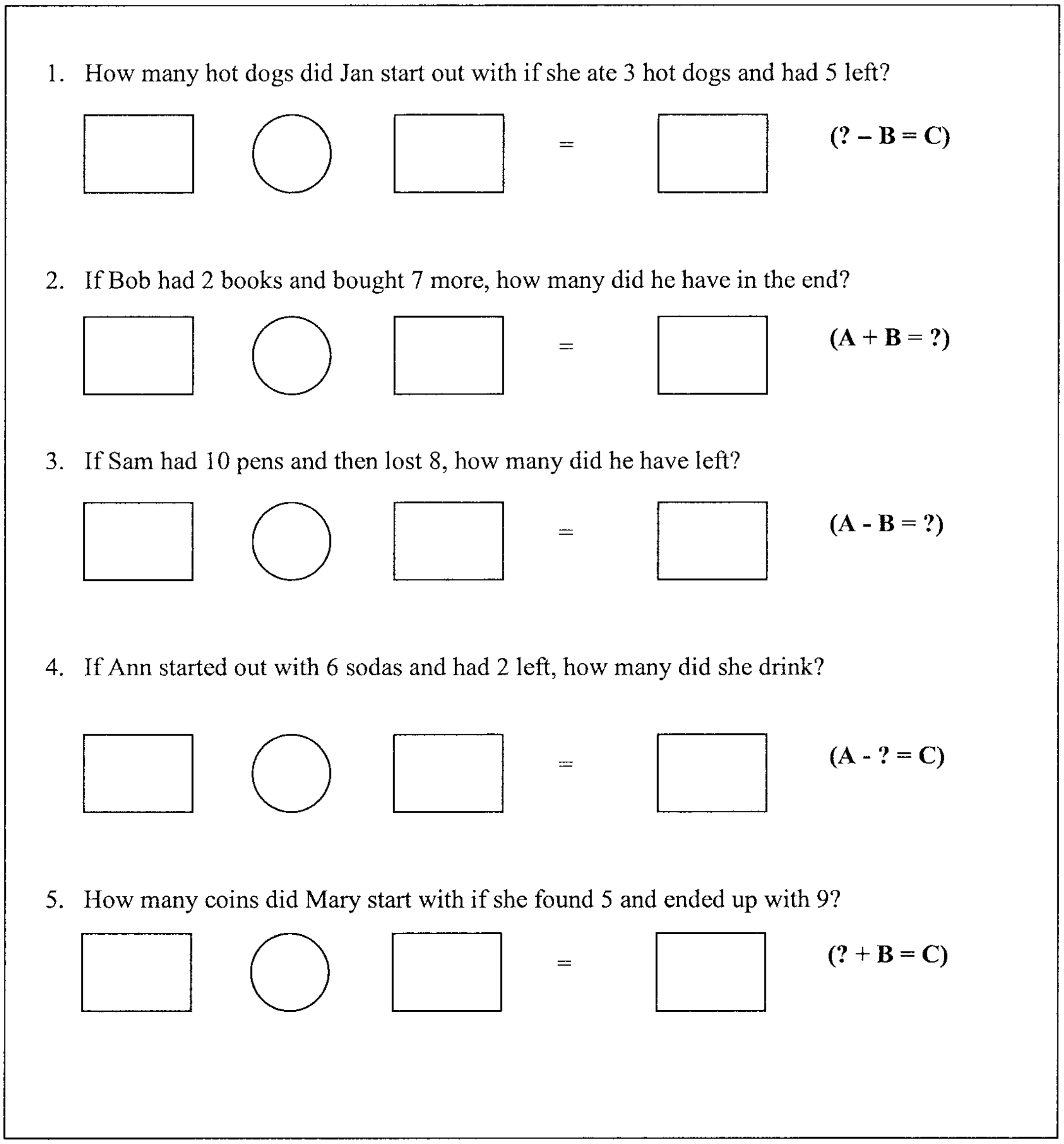

Figure 1. Example of a typical worksheet. Formulas (in bold) are included only for illustrative purposes and were not part of the worksheet.

onstration with five practice problems. The trainer read each problem aloud, presented the verbal prompt (e.g., "How many problems did [name] start out with?"), and described and modeled the correct response. Training trials then began. Each trial consisted of one complete word problem, and 10 trials (excluding remedial trials) were presented each session. One to two sessions were conducted per day. Correct responses were followed by praise. When an error occurred on either the component being trained or any previously trained component, the trainer modeled the correct response directly on the worksheet using a different-colored pen. A remedial trial using a different problem of the same type was then presented. This sequence was repeated for

Table 2
Prompts, Correct Responses, and Incorrect Responses for the Five Problem Components

Initial set	
Prompt	"How many objects did (name) start out with?"
Correct	Appropriate words underlined; number in first box if known or X over box if unknown
Incorrect	Incorrect underline, number, or X; no response in 10 s
Change set	
Prompt	"What happened next?"
Correct	Appropriate words underlined; number in second box if known or X over box if unknown
Incorrect	Incorrect underline, number, or X; no response in 10 s
Operation	
Prompt	"Was that number added or subtracted from the first number?"
Correct	Finger placed under words indicating the operation; correct symbol in circle
Incorrect	Incorrect pointing or symbol; no response in 10 s
Resulting set	
Prompt	"How many objects did (name) end up with?"
Correct	Appropriate words underlined; number in third box if known or X over box if unknown
Incorrect	Incorrect underline, number, or X; no response in 10 s
Solution	
Prompt	A question pertaining to the unknown, as in "How many objects did (name) (start out with, end up with, get, lose, etc.)?"
Correct	Correct answer placed in box with the unknown (indicated by X)
Incorrect	Incorrect answer; no response in 10 s

subsequent errors on remedial trials. A correct response on a remedial trial produced the next training trial.

During instruction on the initial, change, and resulting sets, three training phases typically were conducted unless the participant displayed consistent correct responding before the planned training phase was initiated. First, problems were presented in which the component being trained was always a known quantity, and responses were preceded by a specific trainer prompt. Next, problems were presented in which the component being trained was randomly unknown (i.e., in approximately half of the problems, that component constituted the solution). Finally, problems were presented in which the component being trained was randomly unknown, and no prompt was provided. During training of the operation, only two phases were used—prompted and unprompted—because one of the components always was unknown. The criteria for advancing from one training phase to the next were 100% correct responses on all trained components (including previously trained components) for one session under prompted conditions and 100% correct responses for two consecutive sessions under unprompted conditions. When a student met the unprompted training criterion for a given component, a probe session was conducted and training was begun on the next component.

Interobserver Agreement

A second observer independently scored students' written responses for both training and probe sessions at least once during baseline and each training phase. Interobserver agreement was calculated by dividing the number of agreements on each component part of a problem by the agreements plus disagreements and multiplying by 100%. Mean agreement scores were 99.9% and 99.5% for probe and training sessions, respectively.

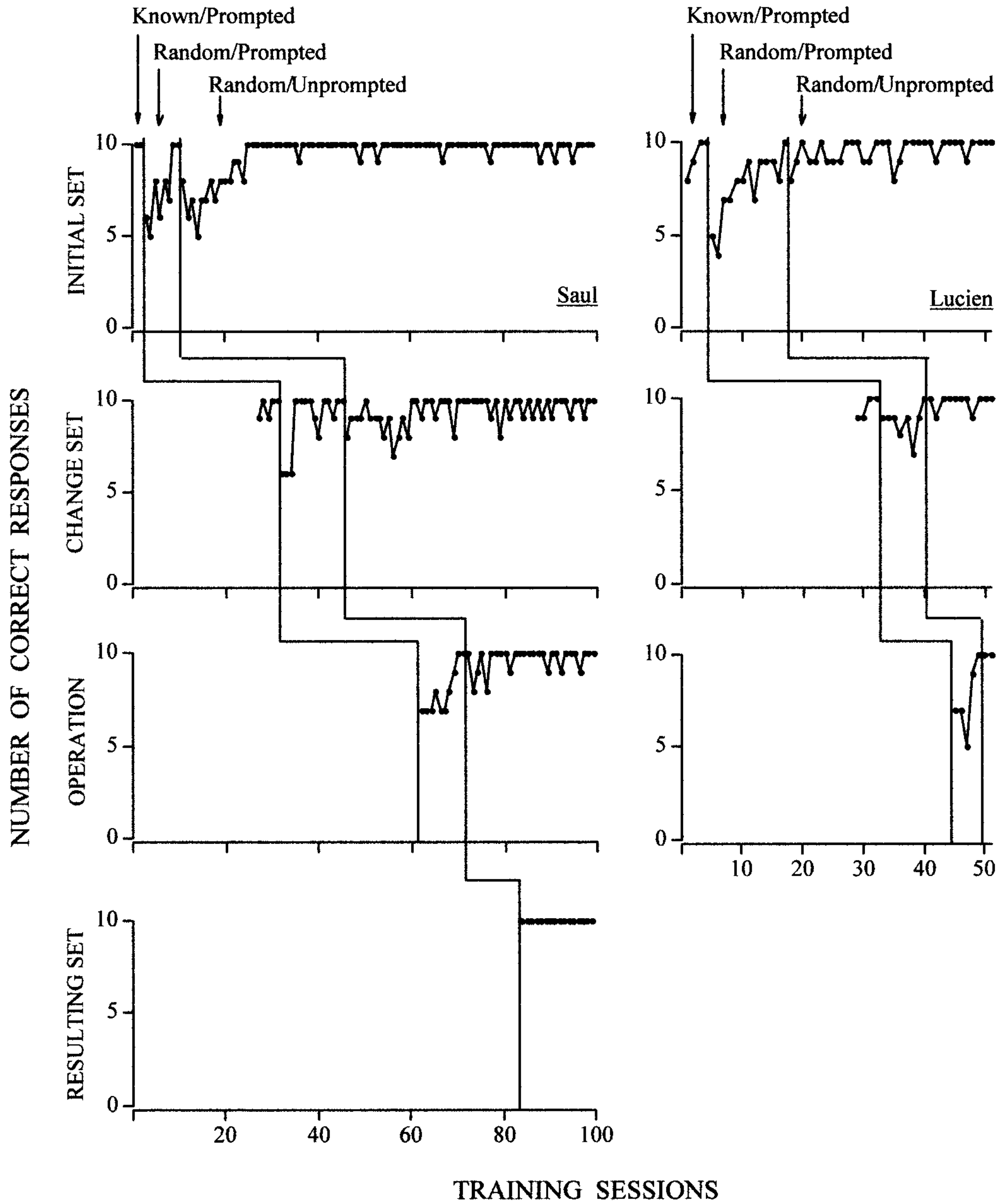

Figure 2. The number of correct responses across training phases for each precurrent component.

RESULTS

Figure 2 shows the training data for each student, expressed as the number of correct responses during training phases for each precurrent component. Both students required fewer sessions to reach criterion as training progressed across components. Saul reached mastery criterion in 26 sessions for the initial set, in 35 sessions for the change set, in 17 sessions for the operation, and in two sessions for the resulting set. Lucien met criterion in 28 sessions for the initial set, in 16 sessions for the change set, and in seven sessions for the operation.

Figure 3 shows probe results for both students across baseline and training conditions

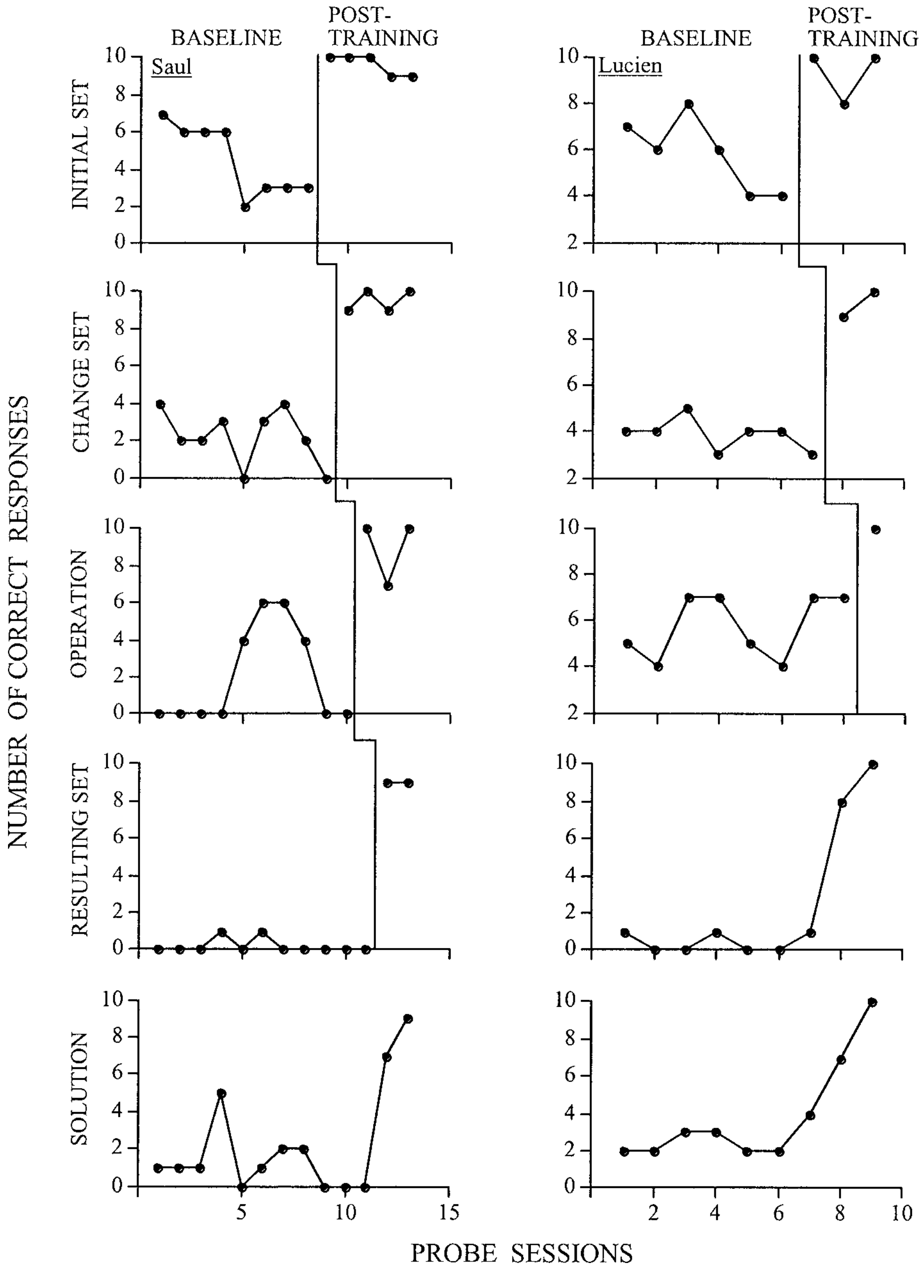

Figure 3. The number of correct responses during mathematics probes across baseline and posttraining conditions.

for each of the five problem-solving components. Data are expressed as number of correct responses. The results show (a) an increase in the number of correct responses on probes following instruction on the respective precurrent (problem-solving) component and (b) an increase in the number of correct solutions (current operants) after the precurrent responses for all components had been established. Saul's mean numbers of correct precurrent responses (of 10 possible) during baseline and posttraining probes, respectively, were 4.5 and 9.6 for the initial set, 2.2 and 9.5 for the change set, 2.0 and 9.0 for the operation, and 0.2 and 9.0 for the resulting set. His correct solutions increased from a mean of 1.2 to 8.0 after the precurrent responses in all components had been established. Lucien's mean numbers of correct precurrent responses during baseline and posttraining probes, respectively, were 5.8 and 9.3 for the initial set, 3.9 and 9.5 for the change set, and 5.8 and 10.0 for the operation. After the precurrent responses in those three components had been established, generalization occurred to the resulting set without further training; correct responses increased from a mean of 1.4 to 10. His correct responses on the untrained solution set increased from a mean of 3.1 to 10 after the component precurrent behaviors had been established.

DISCUSSION

Results of this study showed that teaching students with developmental disabilities a set of precurrent behaviors consisting of the identification of each of the component parts of a story problem resulted in the generative solution of problems. As such, the study represents one of the few experimental investigations of a systematic procedure to teach generative story problem-solving skills to students with developmental disabilities, addressing a principal goal of mathematics instruction.

As discussed by Skinner (1953, 1966, 1968, 1969), problem solving involves an interresponse relation in which the emission of precurrent operants makes the solution (current operant) more probable. In the present case, the number of correct solutions increased for both students after the succession of precurrent responses had been established for each component. The precurrent contingencies can be interpreted as a response chain, but in situations in which it is possible for the current behavior to occur and be reinforced without the emission of precurrents, they can nevertheless function to alter the probability of reinforcement (Polson & Parsons, 1994).

Although contingent praise was used during training sessions to promote the acquisition of the precurrent behaviors, it is possible that reinforcement derived from problem solution may have served to maintain both the precurrent and current responses during probes (when contingent praise was not used). In other words, the precurrent behaviors may have been indirectly reinforced by the solution they prompted. This is consistent with the results of investigations by Parsons (1976) and Parsons, Taylor, and Joyce (1981), in which precurrent collateral behavior was maintained when reinforcement was made contingent on a subsequent current operant. Alternatively, the precurrent and current responses may have been maintained during the probe session because praise was intermittently delivered for on-task behavior (rather than for the precurrent or current responses) and the participants may not have discriminated the different contingencies in effect between the training and probe sessions.

The acquisition of effective precurrent behaviors may have been facilitated by the progressive training sequence that required demonstration of the target as well as all previously trained components. Mayfield and Chase (2002), for example, found that the rate and accuracy of algebra problem solving and novel application were higher for college students who received instruction that incorporated cumulative practice on a mix of previously trained component skills (rules) than for students who received instruction that incorporated simple practice on one component at a time or one session of extra practice. The authors argued that the juxtaposition of different kinds of problems in the cumulative review enabled learning of multiple discriminations for rule application necessary for problem solving with novel rule combinations.

Nevertheless, it is possible that training in the present study may have required less time without the known prompted and unknown prompted phases. The relatively large number of sessions needed to reach criterion during the random unprompted phase suggests that performance may not have been facilitated by the two preceding training phases, but the design did not allow that determination. Similarly, it may be that teaching all components simultaneously rather than sequentially would be more efficient.

Our results are limited in several additional respects. First, because of time constraints, we were unable to examine the extent to which the effects were maintained over an extended period of time. Second, a more complete analysis of the function of the behaviors as precurrents would require a demonstration that correct solutions decrease when the precurrent behaviors were prevented, or that those behaviors were not maintained when they were not followed by a correct solution. Parsons (1976) and Parsons et al. (1981), for example, showed decrements in terminal symbol counting and matching-to-sample behaviors, respectively, when collateral precurrent behaviors were prohibited. It would be difficult, however, to use such preparations in the context of the present study. For example, unlike in the Parsons et al. investigation, the precurrent behaviors could not be prevented because, once learned, they may become covert (Skinner, 1976); indeed, that would be a desirable outcome. In addition, to teach behaviors that are ineffective in producing the current operant seemed counterproductive to the purpose of our applied investigation.

Our purpose was to extend the concept of precurrent operants examined in basic research (Parsons, 1976; Parsons et al., 1981; Polson & Parsons, 1994; Torgrud & Holborn, 1989) to our own problem-solving efforts in developing effective procedures for teaching an educationally significant skill that has proven to be difficult for students with developmental disabilities. The procedure was efficient in that the identification of the basic elements and operations involved in a problem, regardless of their position or sequence, enabled solution of all types of problems within that class. Thus, the procedure enabled students to respond to problems that require a novel synthesis of responses in the presence of a novel stimulus, consistent with Becker, Engelmann, and Thomas' (1975) definition of problem solving.

Our results were limited to simple addition and subtraction story problems and did not encompass all the categories and subtypes of problems represented in various taxonomies (e.g., Riley & Greeno, 1988). However, the procedures could easily be applied to other types of problems and operations. Efficiency might be improved by applying a general case strategy that systematically samples the range of stimulus and response variations in the universe of possible problems (Endo, 2001).

Because story problem-solving skills have been infrequently addressed in behavioral research, some have suggested that they are beyond the reach of a behavioral analysis. Butler et al. (2001), for example, recently characterized the current problem-solving standards for mathematics curricula as demonstrating "a shift from a behaviorist approach of teaching rote learning of facts and procedures to a constructivist approach" (p. 20). Extensions of the current approach in subsequent research may make more prominent the potential contributions of behavior analysis to the acquisition of complex problem-solving skills of all types.

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STUDY QUESTIONS

1. What are the differences between precurrent- and current-operant behaviors? Provide an original example that illustrates the interaction of these behaviors.

2. Explain the importance of a precurrent analysis to the understanding and improvement of problem-solving behavior.

3. Describe the five components into which word problems were divided.

4. How were correct responses defined?

5. What independent variables were included in the training procedures used to establish the precurrent responses?

6. Summarize the results of the study with respect to acquisition of (a) precurrent and (b) current responses.

7. How were the results of the current study consistent with Skinner's conceptualization of problem solving?

8. What useful information might be gained by including a condition in which participants received reinforcement following correct solutions in the absence of any precurrent training?

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