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Explicitly Teaching for Transfer: Effects on the Mathematical Problem-Solving Performance of Students with Mathematics Disabilities

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The purpose of this study was to explore methods to enhance mathematical problem solving for students with mathematics disabilities (MD). A small-group problem-solving tutoring treatment incorporated explicit instruction on problem-solution rules and on transfer. The transfer component was designed to increase awareness of the connections between novel and familiar problems by broadening the categories by which students group problems requiring the same solution methods and by prompting students to search novel problems for these broad categories. To create a stringent test of efficacy, we incorporated a computer-assisted practice condition, which provided students with direct practice on real-world problem-solving tasks. We randomly assigned 40 students to problem-solving tutoring, computer-assisted practice, problem-solving tutoring plus computer-assisted practice, or control, and pre- and posttested students on three problem-solving tasks. On story problems and transfer story problems, tutoring (with or without computer-assisted practice) effected reliably stronger growth compared to control; effects on real-world problem solving, although moderate to large, were not statistically significant. Computer-assisted practice added little value beyond tutoring but, alone, yielded moderate effects on two measures.

Mathematical problem solving, which requires students to apply knowledge, skills, and strategies to novel problems, is a form of transfer that can be difficult to effect (cf. Bransford & Schwartz, 1999; Mayer, Quilici, & Moreno, 1999). This is especially true for students with disabilities, for whom transfer is differentially challenging (White, 1984). To promote mathematical problem solving, we designed a treatment to teach explicitly for transfer. This treatment attempted to increase awareness of the connections between novel and familiar problems by (1) broadening the categories by which students group problems requiring the same solution methods (i.e., promoting a higher level of abstraction) and (2) explicitly prompting students to search novel problems for these broad categories (i.e., increasing mindfulness). We combined this transfer treatment with explicit instruction on problem-solution rules. Previous work (Fuchs et al., in press) has demonstrated the efficacy of these methods for students without disabilities using a whole-class teaching format. In the current study, we were interested in effects on students with mathematics disabilities (MD) using small-group tutoring. To create a stringent test of efficacy, we contrasted the explicit transfer treatment with a computer-assisted practice condition, which provided students with direct practice on alternate forms of our real-world problem-solving measure.

THREE TRANSFER-INDUCING VARIABLES

As conceptualized by Cooper and Sweller (1987), three variables contribute to problem-solving transfer. Students must (1) master the rules for problem solution, (2) develop categories for sorting problems that require similar solutions, and (3) be aware that novel problems are related to previously solved problems. Research has substantiated the importance of mastering rules for problem solution (e.g., Mawer & Sweller, 1982; Sweller & Cooper, 1985). As students master these rules, they allocate less working memory to the details of the solution and instead devote cognitive resources to identify connections between novel and familiar problems and to plan their work.

Cooper and Sweller's (1987) second variable suggests that schemas play a role in transfer. As defined by Gick and Holyoak (1983), a schema is a generalized description of two or more problems that individuals use to sort problems into groups requiring similar solutions. The broader the schema, the greater the probability that individuals will recognize the connections between familiar and novel problems and that transfer will occur. To gain insight into the role schemas play in transfer, Cooper and Sweller questioned eighth graders as they worked novel algebra problems. The researchers coded responses in terms of whether statements reflected schemas (e.g., when faced with a new problem, students reported thinking about how an earlier problem had been solved), and demonstrated that schemas strongly influence performance on problems that fall within the boundaries of those schemas. They also noted, however, that participants' schemas were disappointingly narrow. The challenge in effecting transfer, of course, is to help learners develop broad schemas.

At the same time, it remains unclear how to address Cooper and Sweller's (1987) third transfer-inducing variable: triggering awareness of the connections between training and transfer tasks. Prior work reveals the importance of such

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awareness. For example, using two sets of paired associates, Asch (1969) demonstrated that many students enjoyed no savings in learning one pair that was identical across the lists; only participants who recognized the pair as familiar realized the savings; but once students were told that an old pair might be on the new list, all students demonstrated the expected savings. In this and related studies (e.g., Catrambone & Holyoak, 1989; Gick & Holyoak, 1980; Keane, 1989; Ross, 1989), performance increased when participants were cued to anticipate similarities across tasks. This demonstrates how awareness of the potential connections across novel and familiar tasks is a key ingredient for transfer. Of course, to achieve transfer it is necessary to go beyond cueing by an external agent. Instead, students must independently activate searches for connections between novel and familiar tasks.

THEORETICAL FRAMEWORK FOR BROADENING SCHEMAS AND EVOKING INDEPENDENT SEARCHES

Salomon and Perkins (1989) provide a framework for understanding how to broaden schemas and evoke independent searches for connections between transfer and familiar tasks without need for external cueing. In Salomon and Perkins's terms, mathematical problem solving is a form of high-road transfer, which requires individuals to formulate and search for abstract connections between transfer and familiar tasks. As Salomon and Perkins suggested, the hallmark of high-road transfer is *mindful abstraction*.

To *abstract* a principle is to identify a generic quality or pattern across instances of the principle by deleting details across exemplars, which are irrelevant to the abstract category (e.g., ignoring that an airplane is metal and or that a bird has feathers to formulate the abstraction of "flying things"). Because abstractions, or schemas, subsume related cases, they promote transfer. With *mindfulness*, an individual withholds an initial response and, instead, deliberately examines the task at hand and generates alternative solutions by considering ways the novel task shares connections with familiar tasks. So, with high-road transfer, abstraction provides the bridge from one context to the other; mindfulness is the conscious recognition and effortful application of that abstraction across contexts.

Salomon and Perkins (1989) further describe two forms of high-road transfer. With forward-reaching high-road transfer, the abstraction is generated in the initial learning context; as learners engage in the initial task, they consider other situations where the abstraction might apply. With backward-reaching high-road transfer, abstraction occurs in the transfer situation, where the learner thinks back to previous tasks to search for relevant connections and abstractions. Salomon and Perkins assert that helping students (1) anticipate how abstractions may facilitate success with novel learning tasks (as in forward-reaching transfer) and (2) conduct independent searches for relevant abstractions that apply across tasks (as in backward-reaching transfer) represents an untapped instructional opportunity to explicitly teach students to transfer.

APPLYING THESE FRAMEWORKS TO EXPLICITLY TEACH FOR TRANSFER AND PROMOTE PROBLEM SOLVING

Our problem-solving tutoring treatment was based on Cooper and Sweller's (1987) and Salomon and Perkins's (1989) frameworks. The treatment incorporated two components. The first component was teaching problem solutions for four types of problem structures (see Figure 1). We selected these problem structures because focus groups of third- and fourth-grade teachers had identified these as among 10 essential problem types in the third-grade curriculum.[1] This component addressed Cooper and Sweller's (1987) first variable, teaching rules for problem solution. It is important to note that the problem-solution instruction did *not* focus on superficial problem features, but rather taught students to focus on underlying concepts of the problems.

By contrast, the second component, explicit instruction in transfer, did (at least in part) focus on *superficial* (i.e., defined in the cognitive literature as *irrelevant*, e.g., Ross, 1989) problem features. The explicit transfer instruction was designed to effect abstraction and mindfulness. With respect to *abstraction*, we attempted to broaden students' schemas for sorting problems that require similar solutions. Toward that end, we taught four types of superficial (i.e., irrelevant) problem features, which change problems without altering the problems' structure or solution (Ross, 1989). Our four types of superficial problem features were format, key-word vocabulary, additional question posed, and placement in a larger problem-solving context. In Figure 2, we illustrate how each type of superficial feature changes a sample problem. As shown, the manipulation of superficial problem features affects neither the structure of the problem nor the required solution. We provided students with practice in sorting novel problems according to which superficial problem feature changed and in solving those novel problems. In this way, we promoted the development of broader schemas, which permitted students to recognize that a broader range of problems belonged to a unifying problem structure and thereby required the known solution.

In terms of *mindfulness*, we explicitly taught students the concept of transfer. Moreover, we cautioned students that, when faced with novel problems, they should search for connections to familiar problem structures and for the superficial problem features they knew could change a problem without altering the required solution. This second treatment component therefore encouraged mindfulness in two ways. First, in a forward-reaching manner, as students learned abstractions about how superficial problem features change without altering problem structures or solutions, they could anticipate how those abstractions might help them solve novel problems. Second, in a backward-reaching manner, as they worked on novel problems, they might search to identify changes in superficial problem features so that familiar problem structures, along with their solutions, were more readily recognizable. By broadening schemas and triggering awareness of the connections between familiar and novel problems, this transfer component addressed Cooper and Sweller's (1987) second and third transfer-inducing variables. The combination of problem-solution instruction with

Shopping List Problem Structure

Danny needs to buy things for his science project. He needs 2 batteries, 3 wires, and 4 magnets. The batteries cost $3 each, the wires cost $3 each, and the magnets cost $2 each. How much money does Danny need for his science project?

Half Problem Structure

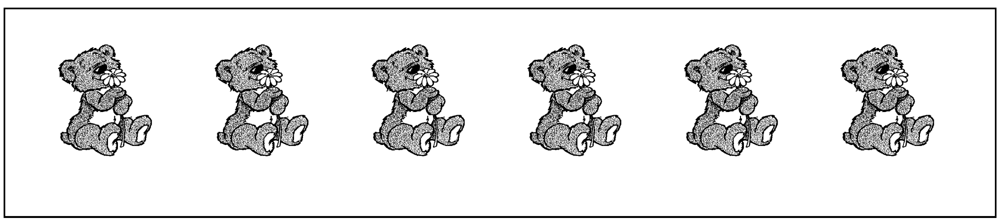
Dave and Todd are going to buy a large box of baseball cards. There are 42 cards in the box. Dave and Todd will each get ½ of the cards. How many cards will each of them get?

Bag Problem Structure

You want to buy some lemon drops. Lemon drops come in bags with 10 lemon drops in each bag. How many bags of lemon drops should you buy to get 32 lemon drops?

Pictograph Problem Structure

Gloria collects teddy bears. She made a chart to show how many teddy bears she had. Each picture of a bear stands for 4 bears.



For her birthday, Gloria got 3 more teddy bears. How many bears does she have now?

FIGURE 1 Examples of four problem structures.

transfer instruction addressed all three transfer-inducing variables. In prior work (Fuchs et al., in press), we verified the contribution of each of the two components for nondisabled students. The problem-solution component effected greater improvement, compared to controls, on immediate transfer measures; the explicit-transfer component effected greater improvement, compared both to control and to the problem-solution component alone, on near-transfer and far-transfer measures.

PURPOSE AND CONDITIONS

In this study, we examined the effectiveness of problem-solving tutoring, which integrated explicit instruction on problem-solution rules and transfer, for enhancing mathematical problem solving among fourth-grade students with MD. To assess the contribution of this treatment, we contrasted its value to computer-assisted practice on real-world problem-solving tasks (alternate forms of what constituted the far-transfer task for the tutoring treatment). Students were randomly assigned to problem-solving tutoring or not and to computer-assisted practice or not, creating four conditions: problem-solving tutoring, computer-assisted practice, problem-solving tutoring plus computer-assisted practice, and control, all of which received (1) the same mathematics curriculum from which the four problem structures (see Figure 1) were selected and (2) the same background unit on approaching mathematical problem solving. We delivered this background unit, which covered checking work, aligning numerals from story problems for computation, and labeling answers, to all students for the following reasons. Students in problem-solving tutoring required this background unit, even though it was not conceptually part of our problem-solving

Original Problem

You want to buy some lemon drops. Lemon drops come in bags with 10 lemon drops in each bag. How many bags should you buy to get 32 lemon drops?

Different Format

- You want to buy some lemon drops.
- The sign at the store looked like this:

LEMON DROPS ON SALE!!!
10 in each bag!!

How many bags should you buy to get 32 lemon drops?

⬭	⬭	⬭	⬭
3	4	2	5

Different Key Word

You want to buy some lemon drops. Lemon drops come in packages with 10 lemon drops in each package. How many packages should you buy to get 32 lemon drops?

Additional Question

You want to buy some lemon drops. Lemon drops come in bags with 10 lemon drops in each bag. How many bags should you buy to get 32 lemon drops? If each bag costs $4, how much money will you spend?

Larger Problem-Solving Context

You saved $37. Your friend saved $12. You and your friend want to buy some lemon drops. Lemon drops come in bags with 10 lemon drops in each bag. You want 32 lemon drops.

1. How much money do you and your friend have?
2. If each bag of lemon drops costs $4, how much money will you spend on lemon drops?
3. If you also buy a hat that costs $15, how much money will you have left?

FIGURE 2 Examples of four superficial problem features.

instruction framework, because it set the stage needed for success in the other four problem-solving units. Students in the remaining conditions required the background unit to eliminate the possibility that outcomes might be attributable to this background unit. Tutoring incorporated explicit instruction (Carnine, 1997), heavy use of worked examples (Cooper & Sweller, 1987), and peer-mediated practice (Fuchs et al., 1997). Computer-assisted practice incorporated guided feedback with motivational scoring.

EXTENSIONS TO PREVIOUS WORK

Most research related to *mindfulness* in mathematics with students with learning disabilities assessed the value of metacognitive planning and organization strategies for approaching word problems with middle and secondary school students. For example, Montague and Bos (1986) investigated the effect of an eight-step metacognitive treatment (i.e., read problems, paraphrase, graphically display known and unknown information, state known and unknown information, hypothesize solution methods, estimate answers, calculate answers, and check answers). Using a single-subject design with six adolescents with learning disabilities, the researchers showed that the metacognitive treatment promoted mathematical problem solving. In the current study, we adopted a different approach to mindfulness by familiarizing students with the notion of transfer, alerting them to the need to transfer skills across situations, and cautioning them to search novel problems to recognize how superficial problem features change without altering the problem's structure or solution.

To help students formulate *abstractions*, instruction typically provides students with opportunities to work problems that gradually broaden the problem-solving context (cf. Prawat, 1989) so that students induce schemas for grouping problems. Some research has, nevertheless, revealed the potential for explicit presentation of the principles to be derived. For example, Schwartz and Bransford (1998) assessed college students' application of psychological principles when students examined psychological studies, received a lecture outlining the principles, or experienced a combination of approaches. Learning was optimized by combining active comparison of contrasting cases with didactic presentation. Work in this area is limited to college-age students without disabilities. In the current study, we combined didactic instruction with opportunities for practice and analysis of contrasting problems. We also extended the relevant literature on schema induction and mathematical problem solving by adopting an innovative approach to highlighting problem features. This approach, which focused students' attention on superficial problem features that alter problems without changing the required solutions, is unusual because it highlights principles that apply across problem structures. For example, students learn that modifying a problem's format does not alter the problem's structure; this facilitates recognition of problem structures, regardless of whether those problems represent the shopping-list problem structure or the half problem structure. By explicitly teaching these principles for ways superficial problem structures vary and by providing opportunities for students to compare contrasting cases illustrating these principles, we attempted to promote a higher level of abstraction than typically is sought, especially for students with disabilities.

The current study also broadened the scope of previous work by investigating mathematical problem solving on a greater range of tasks than is typically studied. We included three measures of learning, with successively greater demands for transfer of the problem-solving tutoring treatment. It is important to note that every problem on each measure was novel, i.e., none had been used during instruction and no cover story resembled those used during instruction. Although the transfer story problems necessarily incorporated the same superficial change *features*, the actual superficial changes differed from those used for instruction.

Story problems represented the four problem structures, structured exactly as those used for tutoring on problem solution rules except that they incorporated *unfamiliar cover stories* and varied quantities. So, for the tutoring condition, this was a test of immediate transfer.

Transfer story problems also represented the four problem structures; however, each problem was novel along two dimensions. It incorporated an *unfamiliar cover story*/quantities, and it *varied (in novel ways) one additional superficial problem feature.*

Our third measure, *real-world problem solving*, provided opportunity for students to solve each of the four problem structures and simultaneously *varied (in novel ways) all four superficial problem feature*s addressed in the tutoring treatment. In addition, the far-transfer test was presented as a *standardized achievement test* to minimize cueing that was irrelevant to the study questions; included *additional problem structures* taught in the district curriculum; and *incorporated irrelevant information*. For the tutoring condition, it was a test of far transfer; however, because it mirrored the tasks practiced within the computer-assisted practice condition, it was an immediate transfer measure for those students.

METHOD

Participants

From three schools in a southeastern city, six special education teachers agreed to have their fourth-grade students with mathematics disabilities (MD) participate. Three teachers served students in full-time special education programs; three provided students one to three hours of special education each day. Teachers nominated 62 students who met two criteria: (1) according to cumulative records, their standard scores on an individually administered intelligence test exceeded 89, and (2) their special education teachers reported that they had MD (i.e., according to state regulations, they demonstrated a discrepancy of at least 1 SD between intelligence and mathematics achievement). To these 62 students, we administered the Test of Computational Fluency (Fuchs et al., 2000), which provides students with three minutes to write answers to 25 second-grade addition and subtraction number facts and algorithms. Percentage of agreement[2] (number of agreements divided by number of items), calculated on 20 percent of protocols by two independent, "blind" scorers, was 99.1. Alternate form/test-retest reliability was 0.90, and the correlation with the Stanford Achievement Test was 0.67 (Fuchs, Hamlett, & Fuchs, 1990). The 40 students who scored 1.5 standard deviations below a regional normative sample were included in the study.

Stratifying so that each condition was represented approximately equally for each teacher, we randomly assigned students so that 10 students were in each of four conditions: problem-solving tutoring with computer-assisted practice, computer-assisted practice, problem-solving tutoring, and control. Over the course of treatment, we lost two students, both from the computer-assisted practice condition, who were removed from school due to behavior problems.

In the four treatment groups, respectively, the number of females was four (40 percent), two (25 percent), three (30 percent), and three (30 percent); the number of students on subsidized lunch was four (40 percent), three (38 percent), four (40 percent), and four (40 percent); the number of African-American students was five (50 percent), four

TABLE 1
Performance Data by Treatment

Variable	Tutoring + Computer X	Tutoring + Computer (SD)	Computer X	Computer (SD)	Tutoring X	Tutoring (SD)	Control X	Control (SD)
WISC[a]	97.20	(12.35)	96.70	(13.25)	94.60	(14.11)	98.80	(12.42)
CRAB[b]	60.00	(41.47)	57.80	(48.88)	64.20	(43.35)	65.10	(40.32)
Test of computational fluency	3.60	(2.99)	5.25	(4.40)	4.50	(3.17)	4.80	(3.88)
Test of mathematics applications	19.20	(7.71)	22.50	(9.07)	21.20	(6.65)	20.90	(7.94)
Arithmetic story problems	25.90	(12.06)	26.75	(13.86)	28.90	(15.25)	27.60	(13.90)
Story problems								
Pre	1.00	(1.70)	4.75	(4.27)	1.60	(2.95)	2.80	(4.44)
Post	28.30	(11.48)	18.88	(14.12)	32.20	(8.82)	11.60	(9.88)
Improve[c]	27.30	(10.98)	14.12	(11.91)	30.60	(7.66)	8.80	(10.25)
Transfer story problems								
Pre	6.63	(7.13)	5.38	(4.95)	3.05	(2.83)	5.18	(4.60)
Post	17.53	(8.98)	9.84	(9.03)	16.08	(7.62)	4.50	(4.16)
Improve[c]	10.90	(4.19)	3.34	(5.66)	13.02	(6.32)	−0.67	(3.57)
Real-world problem solving								
Pre	5.60	(4.48)	8.87	(6.16)	8.30	(8.33)	5.60	(4.34)
Post	18.35	(14.16)	20.63	(16.19)	19.40	(14.68)	9.75	(6.63)
Improve[c]	12.75	(11.05)	11.75	(14.70)	11.10	(14.19)	4.15	(4.69)

[a] Wechsler Intelligence Scale for Children, full scale.
[b] Comprehensive Reading Assessment Battery, words read correctly in three minutes.
[c] Improve is post minus pre.

(50 percent), five (50 percent), and five (50 percent); the number of European-American students was four (40 percent), four (50 percent), four (40 percent), and five (50 percent); the number of Hispanic students was one (10 percent), zero (0 percent), one (10 percent), and zero (0 percent); the number of students with English as a second language was one (10 percent), zero (0 percent), zero (0 percent), and zero (0 percent); and the number of students with problematic class behavior was one (10 percent), one (10 percent), three (30 percent), and two (20 percent). Chi-square tests indicated group comparability on these variables. One-way analyses of variance (ANOVAs) on the full-scale score of the Wechsler Intelligence Scale for Children (Wechsler, 1991), the number of words read correctly in three minutes on the Comprehensive Reading Assessment Battery (Fuchs, Fuchs, & Hamlett, 1989), the Test of Computational Fluency (Fuchs et al., 2000), the Test of Mathematics Applications (Fuchs et al., 2000), and arithmetic story problems (Jordan & Hanich, 2000) revealed no significant difference (see Table 1).

Classroom Mathematics Instruction

All students participated in their classroom mathematics instruction, which was guided by *Math Advantage* (Burton & Maletsky, 1999) and relies on this set of assumptions: every child can succeed at learning; instruction should be balanced among conceptual understanding, connections to prior knowledge, skill proficiency, and problem solving; instruction should incorporate hands-on activities; problem solving is the focus of instruction; reasoning helps children make sense of mathematics; and children learn best when they understand what and why they are learning, when they investigate real-life situations, and when they link concrete experiences to pictorial representations and abstract symbols. Teachers relied almost entirely on this basal. As reported by teachers following the study, they focused less than 10 percent of their mathematics instructional time on problem solving, instead focusing predominantly on computation and concepts/applications skills. When addressing mathematical problem solving, they modeled problem solutions and provided independent practice. Because all four treatment groups were represented approximately in each teacher's classroom, the nature of teachers' instruction was distributed across all four treatment groups and cannot account for differential outcomes.

Approaching Mathematical Problem Solving: A Background Unit Delivered to All Participants

All participating students received a background unit on approaching mathematical problem solving. This unit comprised six lessons (two to three lessons per week, each for 25–40 minutes) on how to approach mathematics word problems. The topics in this unit were: making sure that answers make sense, aligning numbers from word problems for computation, checking work for computational errors, and checking work for word labels, monetary signs, and math symbols. The research assistant (RA), a master's level special educator, conducted these lessons with all students in the resource classes (i.e., 7–14 students per class) regardless of whether students were part of the study. The RA relied on explicit instruction with heavy use of worked examples while she modeled steps for the procedures taught; then, the RA explained partially worked examples, which students completed in dyads and for which they reported answers to the class. Next, children worked in pairs to complete entire problems and checked work against answer keys. Finally, children completed problems independently, checking work against keys.

Experimental Treatments

Timing and Arrangement

Beyond the six-lesson base treatment delivered to students in all four conditions, students in the three experimental groups received supplementary treatment. Problem-solving tutoring involved four additional problem-solving units (one dedicated to each problem structure) for a total of 24 sessions (two per week); computer-assisted practice involved 24 sessions at the computer (two per week); and problem-solving tutoring plus computer-assisted practice involved 24 tutoring sessions plus 24 computer sessions (four per week). Experimental treatment occurred outside classroom math instruction. Tutoring sessions were conducted in available space in the school, in small groups, with two to four students working with the RA. Computer-assisted practice occurred in the library with multiple students working simultaneously at different machines, with the software programmer supervising sessions.

In each of the four six-lesson units, students in *problem-solving tutoring* received two lessons on rules for problem solution during the first week, two lessons on rules for problem solution during the second week, and two transfer lessons plus one cumulative review lesson during the third week (for a total of 24 sessions across the four units). In each unit, the first problem-solution lesson and the first transfer lesson lasted about 40 minutes; other lessons lasted 25–30 minutes. All sessions were scripted, which were studied, not read. In *computer-assisted practice*, students spent equal amounts of time, and sessions were distributed in the same manner, except that every session was dedicated to guided practice on real-world problem-solving tasks, with corrective feedback and motivational scoring. So, in the problem-solving tutoring plus computer-assisted practice condition, students received twice as much supplementary instructional time.

Tutoring

Problem-solving tutoring incorporated two components. The first was *teaching the underlying concepts within and rules for solving each of the four problem structures*: “shopping-list” problems, “half” problems, “buying bag” problems, and “pictograph” problems (see Figure 1). For each problem structure, the RA discussed the meaning of the problem and then taught a solution method. A poster listing the steps of the solution method was displayed. In the first session of each three-week unit, the RA presented a worked example and, as she referred to the poster, explained how each step of the solution method was applied in the worked example. As with all tutoring content, students responded frequently to questions. After reviewing concepts and presenting several worked examples in this way, the RA moved to partially worked examples, where students then applied steps of the solution method while they worked in pairs and reported answers. Sessions ended with students working in dyads, where stronger students helped weaker students solve problems and check work with answer keys. During subsequent sessions within a unit, the RA reviewed the solution method by explaining the poster and showing how the steps of the solution method were applied to a worked example. Then, students spent time in pairs working on problems and checking work. Across sessions of a unit, the proportion of RA-led to peer-mediated activities decreased, so that students spent more time practicing the solution methods. All problems used in the solution sessions were structured as shown in Figure 1; cover stories and quantities varied.

The second component of problem-solving tutoring was *explicit instruction on transfer*. The teacher first taught the concept of transfer. In Unit 1, students were taught that the word *transfer* means *to move* (i.e., just like we transfer [move] to a different school, we can transfer [move] skills we learn to new situations). The RA also presented examples of how children transfer skills; for example, the RA discussed how, as a baby, we learn to drink from a toddler cup, then “move” this skill to a real cup, then “move” this skill to a glass, then “move” this skill to a soda pop bottle. Other examples came from everyday life, and children also volunteered examples. The RA included a math example (i.e., we learn to add working two-digit horizontal problems; then “move” this skill to solve two-digit vertical problems; then “move” this skill to solve three-digit problems; then “move” this skill to the check-out counter of the market where we add the cost of items to figure how much money we need). The RA reviewed the meaning of *transfer* in each subsequent unit.

In addition, the RA taught students that four types of superficial problem features can change a problem without altering its structure or solution. That is, a familiar problem structure can be formatted so that the problem looks novel; can use an unfamiliar key word; can pose an additional question; or can be placed within a larger problem-solving context (see Figure 2). A poster listing the four “Ways In Which Problems Can Change” was displayed. The RA explained the poster, illustrating and explaining each superficial problem feature with a worked example. Then, students classified problems (within that unit’s problem structure) according to which superficial problem feature had changed and explained how the problem seemed different but still represented the problem structure. The RA gradually moved to partially worked examples, where students worked in pairs to apply the solution method to problems that varied superficial problem features. Then, students worked in dyads, where stronger students helped weaker students and checked work using answer keys. Sessions ended with students completing problems independently and checking work using keys. In the second transfer session in each unit, the RA reviewed the four superficial problem features by explaining the poster, showing how the steps in the solution methods were applied to a worked example, and having students work problems in which superficial problem features had changed. Then, pairs worked on problems and checked work, with independent work provided at session’s end. Within a unit, all problems represented the same problem structure (the focus of the unit). Each problem varied one superficial problem feature.

The RA also alerted students to the possibility that novel problems might incorporate changes in superficial problem features and therefore represent a familiar problem structure and solution. The RA reminded students to search novel problems for superficial changes to identify familiar problem structures and apply solutions they knew. The RA interspersed prompts across both transfer lessons of each unit.

Computer-Assisted Practice

Computer-assisted practice was conducted on tasks mirroring the far-transfer measure: real-life problem-solving situations that simultaneously incorporated the four problem structures taught within problem-solving tutoring (as well as other problem structures). After students logged onto the software and identified the problem-solving task on which they currently were working (students could work on the same task across days), the problem-solving task was displayed (see Figure 3); students also had a larger, paper/pencil version of the problem at the computer station. When students clicked on text, the segment was enlarged while the computer read it aloud; when students clicked on "See Video," students saw a video that depicted the problem-solving situation. When students clicked on a question, a new screen appeared, along with an item bank of words, numbers, and mathematical symbols (see Figures 4–5), providing space and tools for students to build responses. (Students could also use the keyboard to create responses.) When students clicked on a word in the item bank, the computer read the word aloud; a second click moved the word onto the "computer paper." Students used the mouse to drag words and other items into place. At any time, students could view their current score, along with a tip (which they could read or listen to) (see Figures 4–5). In iterative manner, students used the guided feedback provided in the tips to improve responses. Scores awarded credit for all aspects of student work, including computation (e.g., adding correctly), communication (e.g., using labels, signs), problem solving (e.g., finding relevant information, creating an organized workspace), and conceptual underpinnings (e.g., using the correct operation), to mirror the scoring scheme of the far-transfer, real-world problem-solving task. To create a game-like atmosphere and enhance motivation, computer-assisted scores awarded more points for each correct feature of responses, with scores ranging to 1,000 for Question #1 and 4,000 for Question #2. At the end of the session, which was timed to approximate the mean time spent per tutoring session, students clicked on (1) "Save Work," in which case they continued working on the same task during the next session, or (2) "Finished," in which case they began the next session with a new real-world problem-solving task (see Figure 3). It is important to note that no reading or writing was required to use the software. The computer read and re-read all words/text as requested by students.

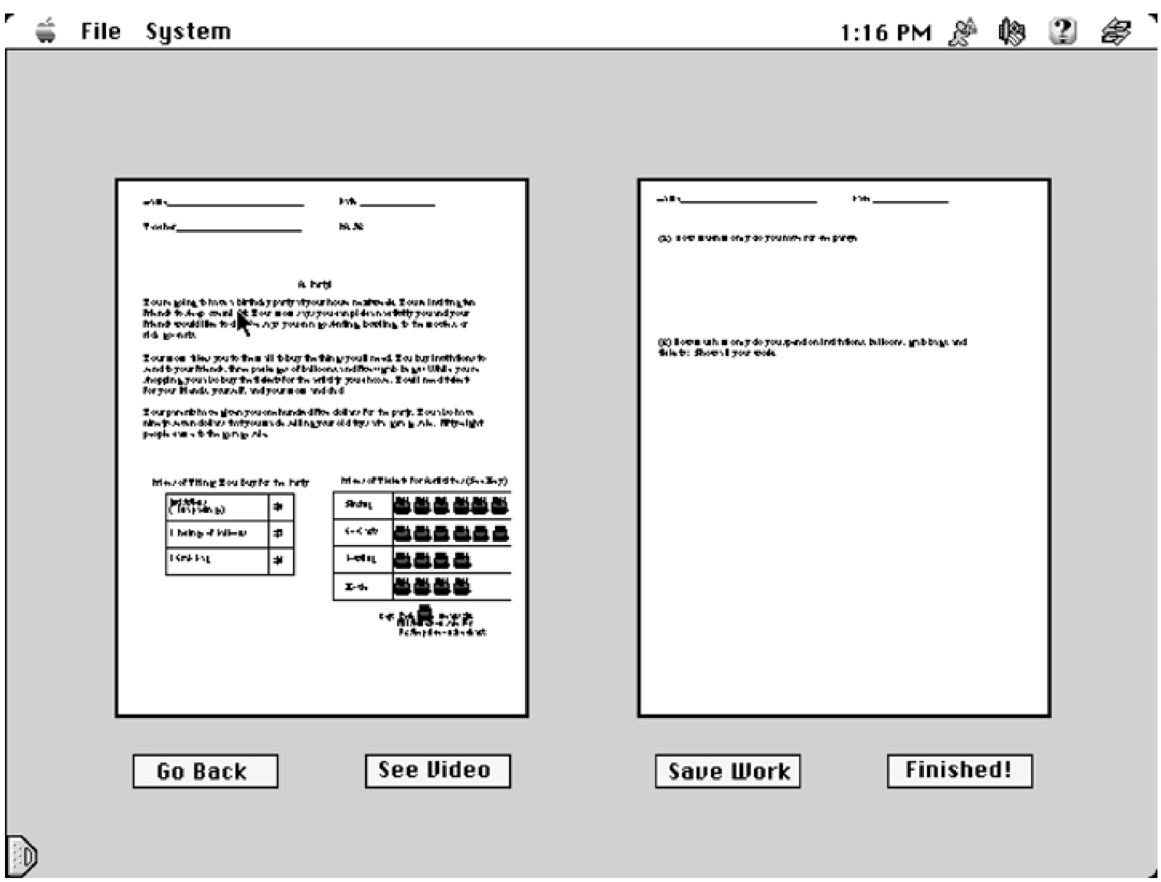


FIGURE 3 Problem presentation in computer-assisted practice.

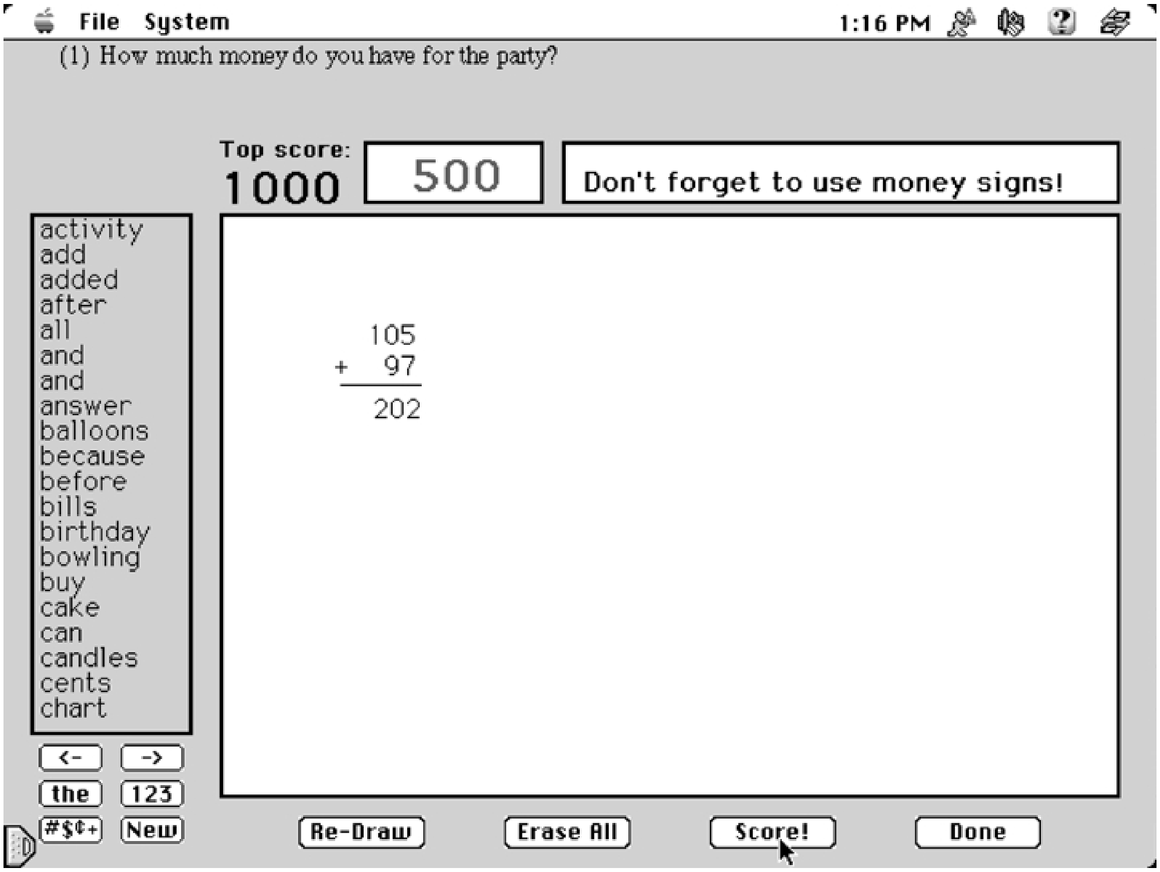


FIGURE 4 "Computer paper" for Question #1 in computer-assisted practice, with item bank, score, and an example of a "tip."

Measures

The three measures were story problems, transfer story problems, and real-world problem solving. Again, please note that every problem on each measure was novel, i.e., none had been used during instruction, and no cover story resembled those used during instruction. Although the transfer story problems necessarily incorporated the same superficial change *features*, the actual superficial changes differed from those used for instruction.

Each measure had two alternate forms; the problems in both forms required the same operations and presented text with the same number/length of words. Story problem alternate forms incorporated the same numbers, as did the transfer story problems alternate forms. Real-world problem-solving alternate forms used similar numbers. In half the classes in each condition, we used Forms A at pretest and Forms B at posttest; in the other half, forms were reversed.

Story problems (four problem structures with novel cover stories) comprised 10 word problems representing the four problem structures taught in tutoring. Across the 10 problems, the maximum score was 43. Cronbach's alpha was 0.95 ($n = 399$); concurrent validity with the TerraNova (CTB/McGraw-Hill, 1997) was 0.58 ($n = 412$); and interscorer agreement, computed on 20 percent of protocols by two independent, "blind" scorers, was 0.99 (number of agreements divided by number of items).

Transfer story problems (four problem structures, novel cover stories, one superficial problem feature varied per problem) comprised seven problems: one shopping-list problem with a novel problem format (information shown in bulleted format, with a selection rather than an open-ended response format); one shopping-list problem with a novel final question (asking for money left at end); one bag problem with a novel key word (*packages* instead of *bags*); one bag problem with a novel final question (comparing prices of two packaging options); one half problem with novel key words vocabulary (*share equally* instead of *half*); one pictograph problem with a nonstandard final question (comparing prices between stores); and one problem requiring students to combine two problem structures (i.e., half and pictographs with a different final question asking for money left). Across the seven items, the maximum score was 47. Cronbach's alpha was 0.92 ($n = 401$); concurrent validity with the TerraNova was 0.55 ($n = 412$); and interscorer agreement, computed on 20 percent of protocols by two independent, "blind" scorers, was 0.96.

Real-world problem solving (all four taught problem structures simultaneously embedded in a real-life problem-solving context, with all four superficial problem features varied and additional elements of novelty) assessed students' application of all four problem structures and all four superficial problem features taught in problem-solving tutoring and practiced in computer-assisted instruction. It incorporated irrelevant information and assessed application of six additional

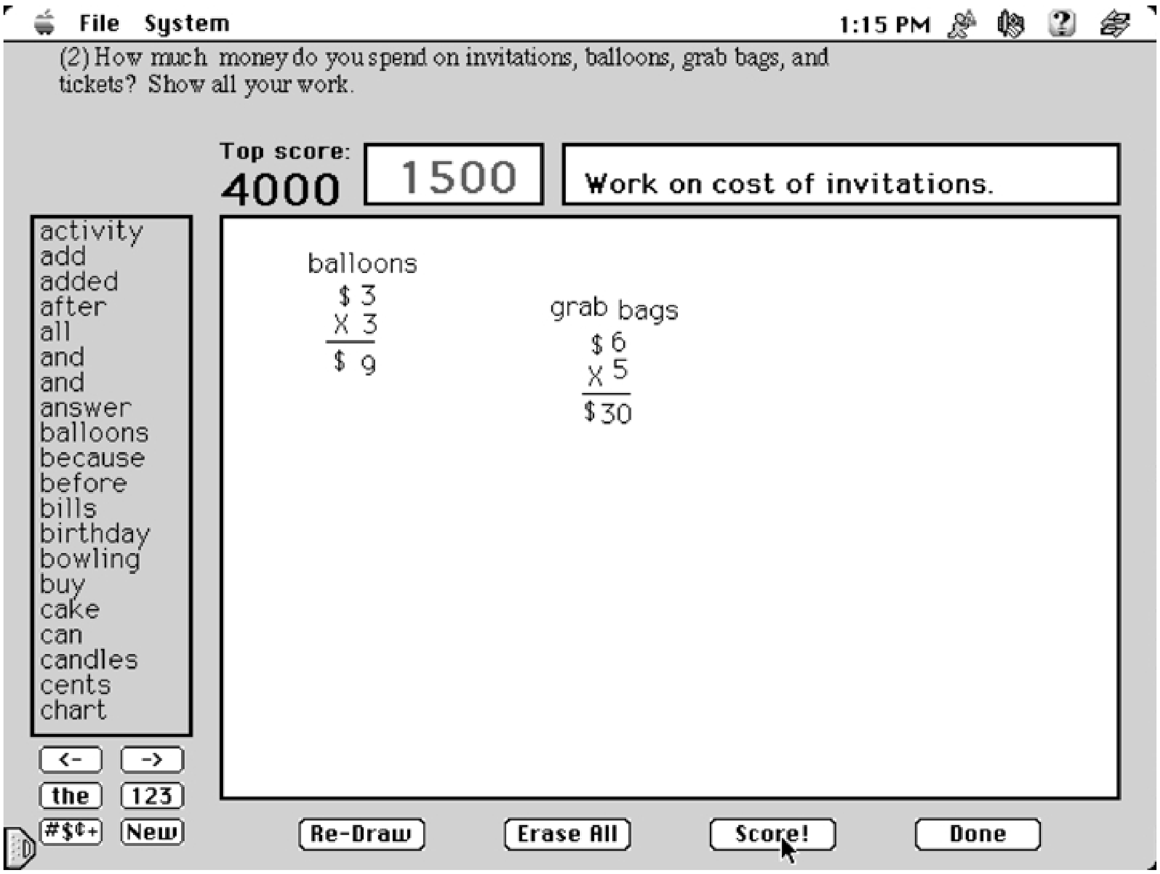


FIGURE 5 "Computer paper" for Question #2 in computer-assisted practice, with item bank, score, and an example of a "tip."

"essential" skills from the district curriculum. In addition, to decrease the probability of associating real-world problem-solving task with problem-solving tutoring, the measure was formatted to look like a commercial test (was printed with a formal cover sheet, all on green paper, with photographs and graphics interspersed throughout the test booklet). Two assessments were constructed to operate as alternate forms: although the context of the problem situations differed, the structure of the problem situation and the questions were identical, and the problem solutions and reading demands were equivalent. The quantities across alternate forms were similar but not identical. For an example of the performance assessments, see Appendix and Fuchs et al. (2000).

Performance was scored according to a rubric adapted from the Kansas State Board of Education (1991) along four dimensions: conceptual underpinnings, computational applications, problem-solving strategies, and communicative value. The original rubric scored responses on a six-point scale; to enhance reliability, we converted this scoring system to award points on a finer basis (e.g., the problem-solving strategies score included points for finding relevant information, accumulating to a total, showing all computation, working the answer in distinct multiple parts, labeling at least half of the multiple parts, and labeling work with monetary and operation signs). The maximum score across the dimensions and questions was 70. Cronbach's alpha was 0.94 ($n = 394$); concurrent validity with the TerraNova was 0.67 ($n = 412$); and interscorer agreement, computed on 20 percent of protocols by two independent, "blind" scorers, was 0.96.

Data Collection

The RA collected data in small groups. A second observer helped supervise all sessions to ensure accurate data collection, to prevent students from copying each other's work, and (for real-world problem solving) to assist with re-readings. Pretesting occurred during the three weeks before the base treatment was delivered; posttesting, during the three weeks following Unit 5. For story problems and transfer story problems, the RA read aloud each item and provided students time to complete work before progressing to the next item. For real-world problem solving, the RA read the entire assessment and, upon request, re-read portions to individuals as they worked. Given work (Fuchs et al., 2000) demonstrating the deleterious effects of students' unfamiliarity with performance assessments, research assistants delivered a 45-minute "test-wiseness" lesson immediately before pre- and posttesting in all study conditions.

Data Analysis

On each outcome measure, we conducted a one-factor ANOVA (tutoring with problem-solving tutoring versus computer-assisted practice versus tutoring plus computer versus control). We conducted parallel analyses on pretreatment scores (to assess treatment group comparability) and on improvement scores (to assess treatment group effects). To follow up significant *F* values, we used the Fisher LSD post hoc procedure (Seaman, Levin, & Serlin, 1991). To estimate the practical significance of effects, we computed effect sizes (ESs) by subtracting the difference between improvement scores and then dividing by the pooled standard deviation of the improvement/square root of $2(1-r_{xy})$ (Glass, McGaw, & Smith, 1981). We also identified the proportion of nonresponders on each measure for each treatment group: the percentage of students whose improvement failed to exceed the control group's mean level of improvement.

RESULTS AND DISCUSSION

Results showed that the pretreatment performance of students in the four conditions was comparable, with ANOVAs conducted on pretreatment scores revealing no significant effects (for story problems, transfer story problems, and real-world problem solving, respectively, F (3, 34) = were 1.98, 1.02, and 0.77, all *ns*). See Table 1 for pretreatment means and standard deviations. When combined with documentation of treatment group comparability on demographics, intelligence, reading, computational fluency, mathematics concepts/applications competence, and arithmetic story problem competence, the finding of no pretreatment differences on the problem-solving measures bolsters the proposition that improvement on the problem-solving measures is not attributable to preexisting differences among the study groups.

Improvement did vary differentially as a function of treatment, at least on two of three measures. For story problems, transfer story problems, and real-world problem solving, respectively, F (3, 34) values were 10.13, $p < 0.001$; 16.02, $p < 0.001$; and 1.11, *ns*. The Fisher LSD post hoc procedure revealed that for story problems and transfer story problems, students in the tutoring with computer-assisted practice group and those in the tutoring group (without computer-assisted practice) outgrew students in the computer-assisted practice group (without tutoring) and those in the control group. On story problems, no other difference was statistically significant. On transfer story problems, students in the computer-assisted practice group (without tutoring) also outgrew those in the control group. See Table 1 for means and standard deviations; Table 2, for effect sizes.

The problem-solving tutoring provided students with explicit instruction on rules for problem solution and explicit instruction on transfer. Findings showed that this tutoring promoted mathematical problem-solving growth among students with MD. On the story problems and the transfer story problems measures, tutoring produced statistically significant improvement compared to a control condition, in which students had received a three-week background instructional unit on how to approach word problems (check that answers make sense, align numerals for computation, check computations, and label work with monetary signs, words, and mathematical symbols). Effect sizes comparing the tutoring condition with this control group were large: 2.10 on story problems and 1.67 on transfer story problems. Therefore, effects were not only reliable but also practically important. Moreover, the proportion of nonresponders was negligible for the two groups of students who received problem-solving tutoring. On story problems, only 1 of 10 (10 percent) students in the tutoring plus computer-assisted practice group failed to make progress that exceeded the control group mean; none of the students in the tutoring group failed to meet this cutoff for responsiveness. On transfer story problems, figures were similarly strong: no student failed to meet the improvement criterion for either treatment group, leaving no nonresponders. By contrast, in the computer-assisted instruction group, five (62.5 percent) of eight students were classified as nonresponders on story problems; four (50 percent) of eight on transfer story problems.

Of course, transfer to real-world problem solving was not statistically significant. The corresponding effect size did, however, exceed a half standard deviation. This figure is in the same range as the effect size (0.63) associated with the computer-assisted practice condition, even though the computer-assisted group spent all of its experimental time practicing problems analogous to the real-world problem-solving task. Moreover, the percentage of nonresponders was only 20 percent for the tutoring treatment, where the real-world problem-solving task constituted far transfer. By contrast, for the computer-assisted practice group, which had direct practice on analogous real-world problems, 62.5 percent of students with MD failed to demonstrate greater progress than the mean of the control group. Although the lack of statistical significance precludes the assertion that the problem-solving tutoring effected far transfer, the large effect size, along with the favorable nonresponder rate for the tutoring treatment, suggest that future research is needed, with larger samples, to explore the reliability of this effect. To conclude otherwise would run the risk of committing a Type II

TABLE 2
Treatment Effect Sizes

	Effect Size					
	Tutoring + Computer vs.			*Computer vs.*		*Tutoring vs.*
Variable	*Computer*	*Tutoring*	*Control*	*Tutoring*	*Control*	*Control*
Story problems	1.28	−0.03	1.90	−1.60	0.51	2.10
Transfer story problems	0.83	−0.27	1.31	−1.31	0.61	1.67
Real-world problems solving	0.07	0.14	0.75	0.05	0.64	0.64

error and discarding a potentially effective treatment in an area where previous work indicates that outcomes are difficult to effect for low-achieving students (Cooper & Sweller, 1987; Fuchs et al., 1999; Mayer, 1998; Woodward & Baxter, 1997).

In any case, findings document the efficacy of this problem-solving tutoring treatment in effecting immediate transfer (i.e., story problems) and near transfer (i.e., transfer story problems) among students with MD. This finding parallels those for students without disabilities, at three points on the achievement continuum, when the problem-solving program was delivered in large-class format (Fuchs et al., in press). As documented by Fuchs et al. (in press), the effectiveness of the problem-solving treatment resides in both components: instruction on rules for problem solution explains effects on story problems, a measure aligned to the problem-solution rules instruction; the explicit transfer component explains effects on the transfer story problems. In addition, findings suggest the need for future research, with larger samples, to explore whether, together, these components may effect the elusive goal of far transfer to real-world problem solving.

What about computer-assisted practice? We designed software to provide intensive, instructive feedback with motivational scoring. Results on real-world problem solving, although not achieving statistical significance, did produce scores that exceeded the control group by a notable 0.64 standard deviation. This might have been expected given that the computer-assisted practice was conducted on tasks directly paralleling the real-world problem-solving measure. More notable were similar effect sizes of 0.51 on story problems and 0.61 on transfer story problems, suggesting that some "downward" transfer did occur. Together, these effect sizes provide the basis for additional research on computer-assisted practice designed to guide students toward enhanced problem solving. Future research should incorporate greater power, not only with larger samples, but also with software that enhances the instructional value of the practice provided. We currently are undertaking this effort because the appeal of improved mathematical problem solving, without the need for expensive adult guidance, is strong.

It is, nevertheless, interesting to note that, with explicit instruction on rules for problem solution and transfer in place, computer-assisted practice (at least as operationalized in this study) provided no added value. On story problems and transfer story problems, the comparison between the tutoring treatments with and without computer-assisted practice revealed small effect sizes (favoring the tutoring with*out* computer-assisted practice). On real-world problem solving, which paralleled the very tasks students practiced via computer, the effect size favoring tutoring plus computer-assisted practice was a disappointingly low 0.14. From a research design perspective, this lends credence to the value of the tutoring treatment because the combined treatment, which failed to effect better growth, incorporated twice the amount of problem-solving work time. Substantively, results are bolstered by the fact that, on story problems and transfer story problems, direct contrasts between the computer and the tutoring treatments reliably favored tutoring: effect sizes comparing tutoring plus computer-assisted practice versus computer-assisted practice alone were 1.28 and 0.83; for tutoring without computer-assisted versus computer-assisted practice alone, 1.60 and 1.31. Consequently, at least as revealed with the software used in this study, computer-guided practice failed to provide a meaningful substitute for or addition to carefully formulated adult tutoring. Perhaps software designed to provide better elaborated instruction would effect better outcomes. Alternatively, it might be used in conjunction with problem-solving tutoring to reduce the amount of teacher time (an expensive resource) required to enhance mathematical problem solving.

In any case, this study provides the basis for a tentative message to practitioners: Teachers may improve the mathematical problem-solving performance of students with MD. To effect this outcome, as suggested in the Fuchs et al. (in press) component analysis and as documented with overall effects in the current study, they should consider teaching problem-solution rules and relying on explicit instruction on transfer. The tutoring treatment used in the current study provides one example of how such instruction might be formulated.

At the same time, the current investigation suffers from important limitations, including two threats to internal validity and two threats to external validity. With respect to internal validity, tutoring was delivered by one research assistant; her instructional style may have accounted for effects. Of course, the tutoring sessions were entirely scripted; the research assistant was not an experienced teacher; and effects were evident for students with disabilities when multiple teachers delivered this treatment in large-group format (Fuchs et al., in press). So, attributing effects to this study's research assistant is not highly plausible. A second threat to internal validity concerns the nature of the tutoring, which was explicit (Carnine, 1997), with heavy use of worked examples (Cooper & Sweller, 1987), and peer mediation (Fuchs et al., 1997). Each of these instructional features has demonstrated efficacy for promoting reading as well as mathematics operations and applications achievement. So, it is possible that a tutoring condition that relied on similarly strong general instructional principles but a different conceptual framework may have effected similarly supportive results. Future studies should be designed to eliminate these alternative explanations.

In terms of external validity, the small sample limits generalizability and, as already mentioned, introduces the possibility of rejecting an effective treatment. At the same time, our participants' reading scores were low (i.e., means approximating 60 whereas typical first graders read 50 words correctly per minute, for a three-minute reading score of 150 on this study's reading measure). As this suggests, the majority of the students with MD in this study experienced comorbidity with reading disability. Prior work shows that this mathematics disability subtype suffers from more pervasive and serious mathematics deficits than students with MD alone (e.g., Hanich et al., 2001; Jordan & Hanich, 2000). On the one hand, this makes the modest success demonstrated in the current study more notable. On the other hand, readers should acknowledge that additional work, not only incorporating larger samples but also contrasting response by MD subtype (with and without reading disability), should be conducted.

NOTES

1. Most available work on MD and mathematical problem solving focuses on arithmetic story problems, one-step story problems that involve sums or minuends of nine or less and represent change, combine, compare, and equalize problem types (Jordan & Hanich, 2000; Carpenter & Moser, 1984; Riley & Greeno, 1988; Riley, Greeno, & Heller, 1983). These problems are representative of the types covered within first-grade school curricula. We decided against using such measures because we were interested in expanding the literature beyond such simple problems to include problem-solving curricula at the third- and fourth-grade levels.
2. We calculated percentage of agreement on all measures, even straightforward ones such as the Test of Computational Fluency, to assure confidence in scoring accuracy.

AUTHOR NOTE

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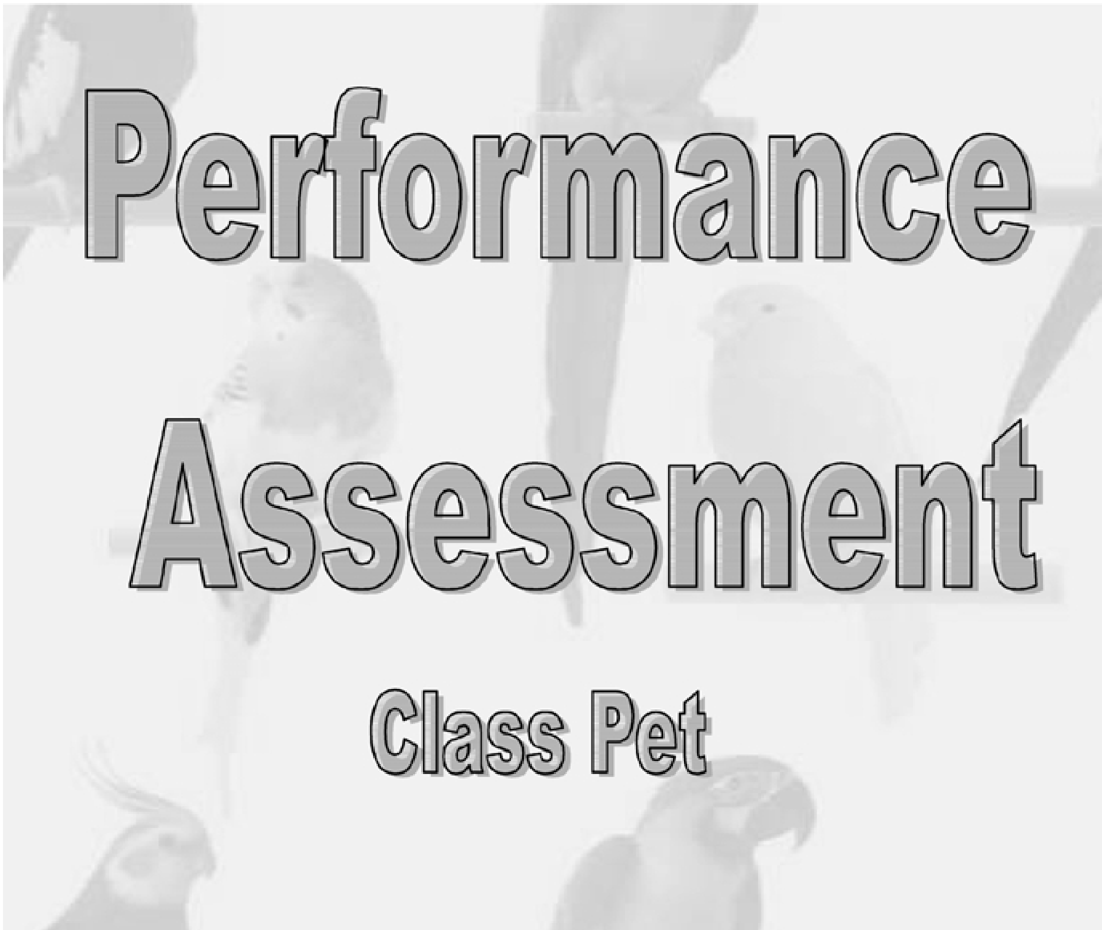
APPENDIX

One of Two Alternate Forms of the Real-World Problem Solving Measure



First Name __ __ __ __ __ __ __ __ __ __ __ __ __

Last Name __ __ __ __ __ __ __ __ __ __ __ __ __

Teacher's Last Name __ __ __ __ __ __ __ __ __ __ __ __ __

Class Pet

Your class decides to buy some parakeets as the class pets. You'll have to buy the birds, a cage, swings, and food dishes for the cage, and enough parakeet food to last for the rest of the year. Your teacher told you that you can also buy other things for the pet center in your classroom.

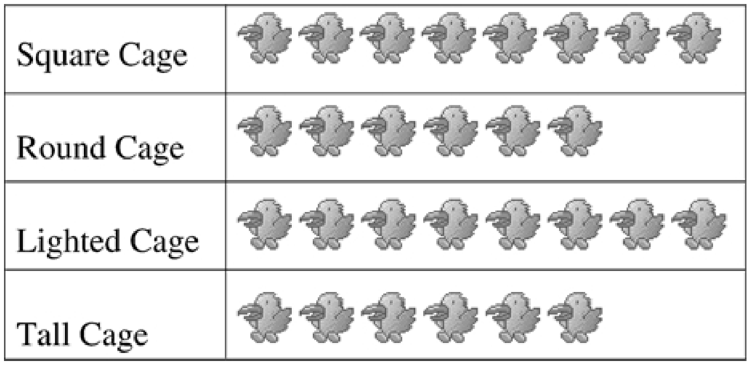
After talking to the pet shop owner, your class decides to buy four parakeets, a large cage, three bird swings, and four food dishes for the cage. Your teacher figures out that you'll need eight pounds of food to last for the rest of the year.

Your class raised one hundred nine dollars from a bake sale and ninety-five dollars from the book fair to buy the birds and supplies. Sixty-two people came to the book fair.

Prices of Birds and Supplies	
1 Parakeet	$14
1 Bird Swing	$8
Bird Food (5 pound can)	$6
1 Food Dish	$2

Go to next page.

Prices of Large Bird Cages (See Key)



Key: Each  means $10.
All cages on sale for 1/2
the price on the chart.

Go to next page.

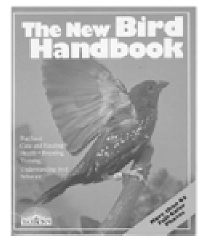
1. How much money do the students have for this project?

2. How much money will the students spend on the birds, the cage, the swings, the food, and the food dishes for the cage? Show all your work.

Go to next page.

3. What other things will the students buy for the pet center in their classroom? How much will the students spend on these other things? What money could they use to pay for these things? (For example, how many $1 bills, how many $5 bills, how many $10 bills.)

4. A book on taking care of birds costs $35. After buying everything else for their pet center, do the students have enough money to buy the book? Explain how you got your answer.



Stop working.

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