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Integrating Reform-Oriented Math Instruction in Special Education Settings

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This mixed-methods study assessed the effects of Enhanced Anchored Instruction (EAI) on the math performance of adolescents with learning disabilities in math (MLD). A quasi-experimental pretest–posttest control group design with switching replications was used to measure students' computation and problem-solving skills on EAI compared to control conditions. Scores on the curriculum-aligned and standardized measures showed improved problem-solving skills but results were mixed for computation. To augment the numerical data, a qualitative inquiry captured day-to-day classroom activities. The findings showed that problem-based curricula such as EAI have the potential for helping students with MLD develop deeper understandings of math concepts but that considerable effort is required to structure and teach these concepts in ways students with MLD understand.

As part of broader reform movement in education that seeks to create and understand *knowledge-centered environments* (e.g., Bransford, Brown, & Cocking, 2000), mathematics teachers are urged to deepen and extend their students' knowledge of math concepts by affording them opportunities to engage in meaningful problem-solving activities. According to the National Council of Teachers of Mathematics (NCTM), these learning experiences should help "students become confident in their ability to tackle difficult problems, eager to figure things out on their own, flexible in exploring mathematical ideas and trying alternative paths, and willing to persevere" (NCTM, 2000, p. 21). An important feature of this reform is the merging of basic skills instruction (i.e., procedural knowledge) with problem-solving instruction (e.g., conceptual understanding) so students become literate in both areas (Ginsburg, 1998; Hiebert et al., 1997). Results from the National Assessment of Educational Progress (NAEP) suggest that the emphasis on problem solving may be paying off as eighth-graders scored higher in 2005 than in any previous year since the test was administered (Perie, Grigg, & Dion, 2005).

Special educators have also advocated for changes in instructional practices for students with learning disabilities in math (MLD) that reflect a more balanced approach between problem-solving and basic skills instruction (e.g., Jones, Wilson, & Bhojwani, 1997; Woodward & Baxter, 1997; Woodward & Montague, 2002). Although important research in special education has uncovered effective strategies for improving the math achievement of students with MLD in computation (e.g., Cawley, Parmar, Yan, & Miller, 1998; Cawley, Parmar, Foley, Salmon, & Roy, 2001; Witzel, Mercer, & Miller, 2003) and problem solving (e.g., Butler, Beckingham, & Lauscher, 2005; Jitendra, DiPipi, & Perron-Jones, 2002; Maccini & Hughes, 2000; Montague, 1997; Parmar, Cawley, & Frazita, 1996), questions still remain concerning both the adequacy of instructional strategies and the richness of the math content used with low-achieving students (Woodward, 2004).

The first question involves the extent to which teaching methods in special education settings are aligned with those used in general education math classrooms. The success of students with MLD to learn from general education curricula and ultimately to participate meaningfully in inclusive math classrooms will depend on how well they are prepared to engage in problem-centered explorations. The need for such an alignment is especially important for 40 percent of 12- to 17-year-old students with learning disabilities who still spend 21–60 percent of the time in special education settings (U.S. Department of Education, 2005). The challenge for special education teachers is to structure lessons in ways that provide opportunities for students who may lack critical conceptual knowledge and sophisticated recall strategies to develop their problem-solving skills, as required in transition settings (e.g., general education, work, postsecondary), while maintaining an emphasis on basic skills, as warranted by the students' disability.

The second issue relates to the ambitious curricular standards and the high performance expectations that have been set for all students in math by government initiatives, the most recent of which is the No Child Left Behind Act of 2001 (NCLB; 2002). These expectations are especially evident in the performance criteria set by the NAEP. According to NAEP, middle schools students who score at the *Basic* level "should complete problems correctly with the help of structural prompts such as diagrams, charts, and graphs" and include "the appropriate use of strategies and technological tools to understand fundamental algebraic and informal geometric concepts in problem solving" (p. 20). Thus, the new standards call for a range of skills beyond procedural competency, which probably helps to explain why 69 percent of students with disabilities in eighth grade scored below *Basic* performance levels on the NAEP compared to 28 percent of students without disabilities (Perie et al., 2005).

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To address both concerns, we have developed a pedagogical approach called *Enhanced Anchored Instruction* (EAI) to help boost the problem-solving skills of low-achieving adolescents. Modeled after *anchored instruction* (AI) (Cognition and Technology Group at Vanderbilt, 1990; Cognition and Technology Group at Vanderbilt, 1997; Goldman, Hasselbring, & Cognition and Technology Group at Vanderbilt, 1998), EAI immerses students directly in problems that are delivered in a combination of multimedia and hands-on contexts. Scaffolds built into the software and its applications have proved important for students with MLD who often need additional support and practice to adequately acquire and retain more complex math concepts. Previous experimental and quasi-experimental studies with students at various skill levels have yielded medium-to-large effect sizes (η^2) on curriculum-aligned problem-solving tests (.31–.79) and transfer tasks (.14–.38) (Bottge, 1999; Bottge, Heinrichs, Chan, & Serlin, 2001; Bottge, Heinrichs, Mehta, & Hung, 2002).

Instructional foundations of EAI are rooted in problem-based learning (PBL), which is a popular method used in medical education and other professions for teaching students how to solve problems in applied situations (Gijbels, Dochy, Van den Bossche, & Segers, 2005). The core characteristics of PBL (Barrows, 1996) are much like those in EAI and include the following: (1) Instructors use probing questions to guide student understanding of authentic-like problems; (2) Students work together in small groups to discuss, test, and find solutions to the problems; and (3) Instructors provide in-depth instruction on skills and concepts as students need them. Thus, both EAI and PBL afford students multiple opportunities to practice their skills in several problem contexts, an important requisite for skills transfer (Brown, Collins, & Duguid, 1989; Greeno and the Middle School Mathematics Through Applications Project Group, 1998).

To date, studies using EAI have focused primarily on students with MLD whose skills were advanced enough to enable them to participate meaningfully in general education settings. In those cases, the special education teachers provided supplemental support to math teachers who planned and delivered the instruction. In this study our goal was to test the effects of EAI in special education settings where special education teachers were solely responsible for the instruction of their students with MLD. Specifically, the study was designed to answer the following questions:

1. Does a reform-oriented instructional method (i.e., EAI) taught by special education teachers in self-contained settings lead to improved math skills of adolescents with MLD?
2. What did teachers identify as key teaching and learning factors that may have produced the quantitative results?

METHOD

Research Design

A mixed-methods approach (Hanson et al., 2005; Mertens, 2003; Johnson & Onwuegbuzie, 2004) was used to address the two research questions. To answer the first question, a pretest–posttest control group design with switching replications assessed the effects of EAI on the math skills of students. According to Shadish, Cook, and Campbell (2002), the use of this design rules out most threats to internal validity. The only alternative interpretation would involve a pattern of historical changes that match the time sequence of the treatment introductions. The design is indicated in the following way using standard notation:

Instructional Sequence A	O_1	X	O_2		O_3
Instructional Sequence B	O_1		O_2	X	O_3

Teachers were randomly assigned to either instructional sequence A or B with two teachers and their students participating in each sequence. A test designed to measure what students were learning from EAI was administered to students in both sequences in three waves. After all students took the pretest O_1, teachers in sequence A taught their students with EAI while teachers in sequence B taught students using their typical methods. To assess what they learned, the teachers administered posttest O_2 to students in both sequences. Thus, the first segment of the study (O_1–O_2) followed a pretest–posttest control group design.

In the next phase of the study, teachers in sequence A went back to teaching their usual curriculum while teachers in sequence B taught with EAI. Then students in both groups were tested for a third time (O_3). This test wave served two important functions. First, it assessed how much problem-solving knowledge students in sequence A retained after a period of typical instruction. Second, O_3 showed whether the performance pattern of students in sequence B (O_2–O_3) replicated that of students in sequence A (O_1–O_2). In addition to the repeated measure, two standardized subtests were administered to students in both sequences prior to and following each testing-teaching sequence (not shown).

To answer the second research question (i.e., practices that may have produced the quantitative results), we used a multiple case study method to analyze the teachers' instructional practices and their students' responses to them. Case studies are useful for studying interventions or innovations, particularly when they substantiate or generate outcomes for improved practice (Toma, 2006). Together with the experimental findings, data sources from each of the four teachers were used to identify and describe the key learning factors that may have produced the quantitative findings. Data sources included online logbooks in which the teachers described their instructional activities, notes from classroom observers, and permanent products such as lesson plans and student work samples. Elements of these data were initially coded as relating to elements of a theoretical model for teaching and learning mathematics (Bottge, 2001). A second member of the research team reanalyzed these data to confirm the original findings and to finalize the explanatory examples.

Participants

Four special education teachers, all European American and female, were responsible for their students' math instruction.

Two of the teachers had master's degrees in special education, one teacher had a master's degree in curriculum and instruction with emphasis on integrating the arts into the curriculum, and one teacher had a bachelor's degree in elementary education. Teaching experience ranged from 3 to 37 years. All four teachers were certified in special education and were solely responsible for all of their students' math instruction. Prior to the study the teachers spent 2 days learning how to teach with EAI as part of a 5-day summer workshop on using instructional technology. A middle school math teacher, experienced in teaching with EAI, led the EAI workshop. Two special educators were also on hand to answer questions about issues specifically related to teaching EAI to students with MLD.

A total of 100 students from three middle schools and one high school participated in the study. Table 1 provides demographic information of the students who were in each instructional sequence. All of the students were receiving special education services for MLD in self-contained special education classrooms because their math skills were considered too low to participate meaningfully in inclusive math classes. Students were identified as having a learning disability because they had displayed a severe discrepancy between intellectual ability and academic achievement (Washington State Legislature [*WAC 392–172-126*], 2006). The tables showing this discrepancy were developed using a regressed standard score discrepancy method.

TABLE 1
Description of Students by Instructional Sequence

	Sequence A		*Sequence B*		
	n	%	*n*	%	*Total N = 100*
Gender					
Boys	34	62	30	67	64
Girls	21	38	15	33	36
Grade					
6	10	18	10	22	20
7	7	13	15	33	22
8	14	25	20	44	34
9	8	14			8
10	7	13			7
11	7	13			7
12	2	4			2
Ethnicity					
European American	39	71	26	58	65
African American	5	9	7	16	12
Hispanic	7	13	11	24	18
Native American	2	4	1	2	3
Asian American	1	2			1
Other	1	2			1
Disability/Service area *					
LD Math	52	95	44	98	96
LD Reading	35	64	37	82	72
LD Written language	40	73	39	87	79
EBD	6	11			6
CD	2	4	3	6	5
S/L	1	2	12	25	13
HI (ADHD) **	10	18	14	29	24
Subsidized lunch	35	64	22	49	57

*LD = Learning Disability; EBD = Emotional/Behavioral Disability; CD = Cognitive Disability; S/L = Speech/Language.

**OHI = Other Health Impaired (ADHD = Attention Deficit Hyperactivity Disorder).

In sequence A, one teacher (bachelor's degree in special education) taught three math classes of students in grade 6, 7, and 8 ($n = 31$). The other special education teacher (master's degree in special education) in sequence A taught four classes of high school students in mixed grade levels ($n = 24$). In sequence B, one teacher (master's degree in curriculum and instruction) taught four classes of students, two that combined students in grades 6 and 7 and two that contained seventh grade students only ($n = 35$). The other teacher in sequence B (master's degree in special education) taught one class of students in grade 8 ($n = 10$).

Pretest scores on the Iowa Tests of Basic Skills (Form A; University of Iowa, 2001) confirmed the low math achievement of the students. Median national percentile ranks of students by grade level ranged from 6 to 11 on the Problem Solving and Data Interpretation subtest and from 5 to 8 on the Computation subtest. In addition to their math disability, from 72 percent to 79 percent of the students were identified as having a disability in reading or written language. On average, students in sequence A received 9.5 hours of special education services per week compared to students in sequence B who received 13.5 hours of service. More than half of the students (57 percent) received subsidized lunch. In interviews, teachers provided anecdotal information indicating that English was the second language for some Hispanic students and that some parents spoke Spanish exclusively in their homes.

Instruction

Teachers were provided lesson plans for teaching *Kim's Komet* and asked to teach with their regular curriculum during typical instruction. Teachers were urged to spend about the same number of class periods in each instructional sequence. Class periods for each teacher were 50 to 60 minutes. Teachers were expected to teach each sequence for about 4 weeks, but several factors such as school activities, teaching styles, and the severity of student disabilities all had an effect on the length of the teaching sequences. Although each teacher taught both sequences for about the same number of days, teacher logs and classroom observations revealed that instructional sequences ranged from 21 to 30 days.

Kim's Komet Instruction

Kim's Komet is one episode in a series of video-based anchors called the *The New Adventures of Jasper Woodbury* (The Learning Technology Center at Vanderbilt University, 1997). Originally on videodisc, the updated version includes both a student and a teacher CD. According to the instructor manual, the purpose of *Kim's Komet* is to help students develop their informal understanding of pre-algebraic concepts, such as linear function, line of best fit, variables, rate of change (slope), and reliability and measurement error. Foundation skills needed to solve this problem include computation with whole numbers and decimals.

The video anchor involves two girls who compete in a Grand Pentathalon that requires competitors to predict where on a ramp they should release their cars to navigate five tricks attached to the end of ramp straightaway: double hump, short jump, loop-the-loop, and banked curve, and long jump (Figure 1). In the first section of *Kim's Komet*, students learn how to calculate speeds when times and distances are known. They do this watching the time trials in the video held the day before the Grand Pentathalon. The challenge is to identify the three fastest qualifiers in three regional races, where times

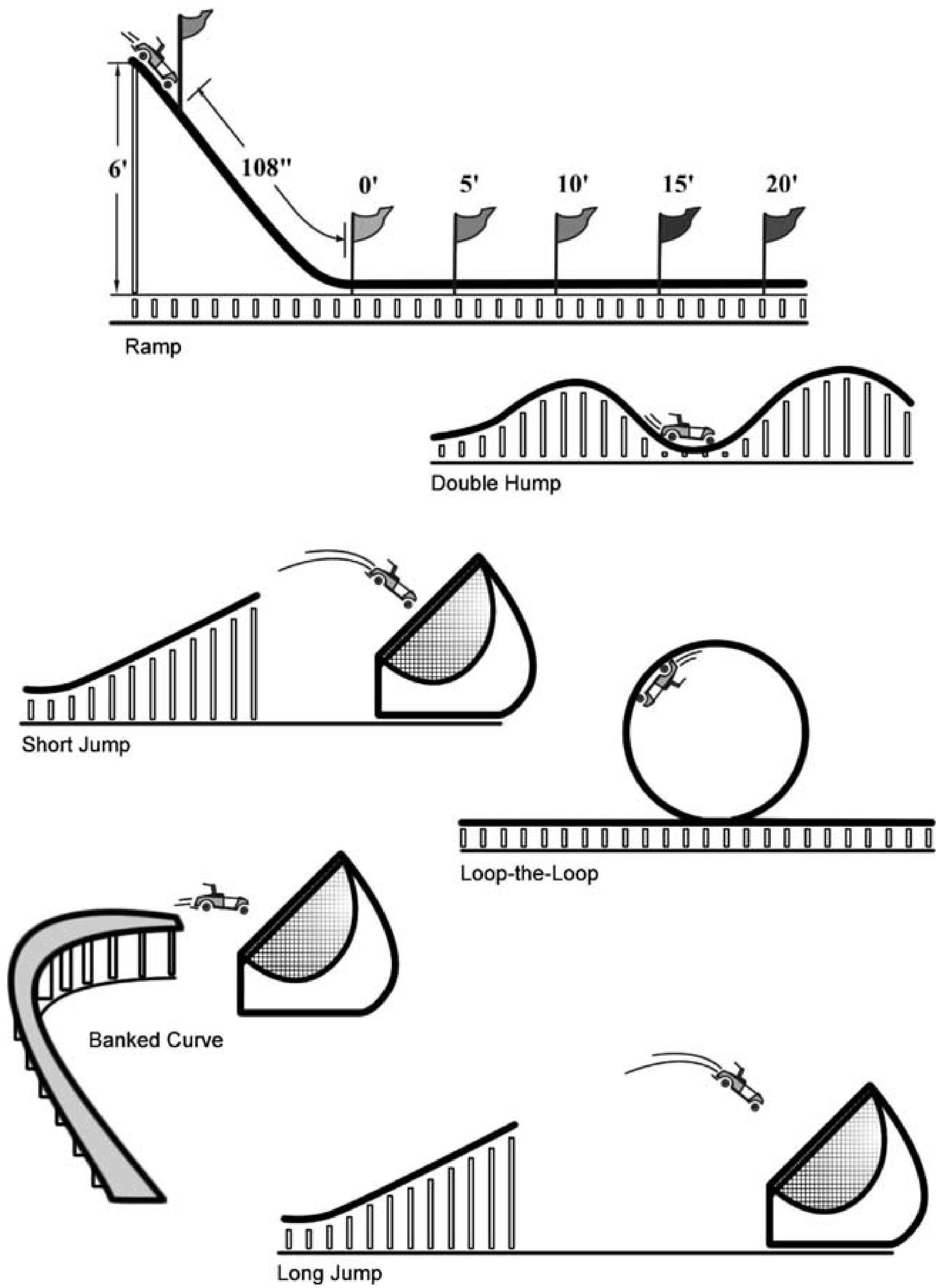


FIGURE 1 Ramp and five tricks in the Grand Pentathalon.

and distances are known but the distances vary. For example, students explain whether a car that travels 15 feet in 0.9 seconds is faster or slower than a car that travels 20 feet in 1.3 seconds.

The next challenge asks students to use their own stopwatches to time Kim's car in time trials prior to the Grand Pentathalon. The software allows students to pick various release points (i.e., heights) on the ramp so they can compute the speeds of Kim's car along a length of straightaway. Eventually the students realize that they should time Kim's car on the straightaway, where the car's speed is relatively constant, rather than on the ramp, where the car is accelerating. After computing these speeds, students plot on their graph the speed of Kim's car for each of the release points and then draw a line of best fit. Students will use this line to predict speeds for all possible release points.

On the day of the Grand Pentathlon, the teachers revealed to students the critical speed range of Kim's car for each of five tricks, which are attached to the end of the straightaway. Students earn points for helping Kim successfully accomplish each trick. The software enables students to enter the height of the release point for each event and to watch Kim as she releases her car from that height. If students provide Kim with the correct release point, they can watch as Kim's car successfully navigates the trick. However, when speeds and release points have been incorrectly computed, they will see Kim's car crash.

After students helped Kim in *Kim's Komet*, they participated in their own pentathlon competition with a full size track and the five events like those shown in the video. Individuals in the community built the ramp, straightaway track, and tricks for the school according to plans drawn by a middle school technology education teacher. Students made their own cars out of wood according to specifications (e.g., width, length, wheelbase) that were matched to those required for the ramp. At the beginning and end of the straightaway, an infrared detector measured time, in thousandths of a second, for the students' cars to travel from one end of the straightaway to the other. Using these times, students made their own graphs showing the speeds of their cars for each release point on the ramp. Students used their graphs as they did in *Kim's Komet* to help them predict where on the ramp to release their cars for achieving the speeds necessary to successfully navigate the stunts at the end of the straightaway. Because each student's car differed slightly in size and weight, each student had to make their own graph.

The teacher logbooks and observational data described how teachers conducted their lessons. Teachers afforded students time to discuss their ideas about how best to solve each subproblem, such as predicting speed based on release points on the ramp. When students had difficulty understanding how to graph variables, the teacher directly taught the labels for each axis and how to plot the data points. Teachers also spent considerable time on the hands-on applications, such as helping students design and make their cars. Teachers reported having to manage less off-task behaviors during the time trials and pentathlon competition when students were highly motivated.

Typical Instruction

Much of the instruction at all four schools stressed survival math skills. Instruction usually began with teachers reviewing problems from the previous day. This was followed with a short explanation of a new skill or concept. After a brief discussion, students worked independently or in pairs to practice their skills. During this time, the teachers monitored student work and managed behaviors. In addition to working on math skills, teachers reported that one of their main goals was to build their students' self-confidence. As one teacher wrote, "They no longer believe they can do anything math related."

Students at the three middle schools worked on practice sheets from workbooks or on teacher-developed materials. The Connected Math Project (CMP) (Pearson Prentice Hall, 2004) was the most widely used math series in the state where the study was conducted. Thus, teachers taught selected parts of it because they wanted their students to learn as much as possible what the students in regular classrooms were learning. However, teachers reported they were only able to adapt some of the curriculum because the series was too language based for their students, most of whom also had reading disabilities. Instructional topics focused on several areas, such as identifying fractions, understanding equivalent fractions, adding and subtracting fractions, understanding and computing with decimals, understanding percent, ratios and proportions, understanding and computing units of measurement, and making stem-and-leaf plots based on data series. Students at the high school level worked in a pre-algebra textbook because they were preparing for the Washington Assessment of Student Learning (WASL) state tests. Most of the instructional time was devoted to teaching integers and solving single-step equations.

Instrumentation

Kim's Komet Problem-Solving Test (KKPST)

The 36-point *KKPST* is a demanding test specifically designed to test concepts taught during *Kim's Komet*. The test consists of constructed-response test items measuring knowledge of mathematics contained in the standards recommended by the National Council of Teachers of Mathematics (NCTM) (i.e., Numbers and Operations, Problem Solving, Communication, and Representation). These concepts align closely with the NCTM Algebra Standards for grades 6–8. The *KKPST* assessed students' ability to estimate and compute rates, times, and distances when one of the values was unknown. To figure out the correct answers, students had to understand figures, interpret data from tables and graphs, construct their own tables and graphs, recognize relationships among these data, and make predictions based on their solutions. Some of the problems were in standard word problem format with the reading level kept at or below the fourth grade.

The *KKPST* went through cycles of refinement based on student performances in previous research (Bottge, Heinrichs, Mehta, & Hung, 2002; Bottge et al., 2004; Bottge, Heinrichs, Chan, & Serlin, 2001; Hung, 2005) and on suggestions from math and assessment specialists (i.e., math teachers, math researchers, test consultants). This test has also served as the basis for a recent study that compared the response patterns of students using mixture item response theory (IRT) models (Cohen & Bottge, 2006). Sets of problems were weighted according to their complexity and the contribution they were expected to make in solving the overarching problem. Within each set, items were awarded full or partial credit, which made it possible to analyze student work at both the item and concept levels (Lester & Kroll, 1990; Shafer & Romberg, 1999). In previous research that sampled students with a wider range of abilities (i.e., students with and without disabilities), the concurrent validity correlation coefficient of the *KKPST* based on pretest scores of the ITBS Problem Solving and Data Interpretation subtest was.52, which appears acceptable given that the range of mathematics concepts sampled by *KKPST* was more restricted than that sampled on the ITBS.

Overall, students could earn partial or full credit in six major categories, with scale weights based on more than 20 procedures. Interrater reliability was 98 percent for 20 percent of the test protocols randomly selected from each test wave. Reliability was calculated by dividing the number of agreements by the total number of agreements and disagreements and multiplying by 100 (Sulzer-Azaroff & Mayer, 1977). Internal consistency of test items (Cronbach's coefficient alpha) was .89.

Figures 2 and 3 show several test items from the *KKPST*. Item #1 is in the form of a typical word problem and asks students to calculate time when speed and distance are known. Item #3 shows a line graph with distance labeled on the *y*-axis and time on the *x*-axis. Students answer two questions by reading the data line representing the relationship of the two variables. Item #5 shows a car ramp with the height of the ramp and the lengths of the straightaway labeled. Students use the drawing and information in the table to calculate the speed of each student's car. Then they answer a series of questions about who has the slowest and fastest car in each region. Most difficult are items #6 and #7, which ask students to calculate and graph the speeds of cars released from several heights on a ramp. This problem is extremely challenging, because students must first understand that speed is relatively constant on the straightaway, in contrast to speeds on the ramp where the car is accelerating. Using this information, they figure out the speed of the cars and then graph their data, label the axes, and draw a line of best fit for predicting speeds of cars released from any height on the ramp.

Standardized Tests

The Iowa Tests of Basic Skills (Form A; University of Iowa, 2001) math subtests (Problem Solving and Data Interpretation, Computation) measured math skills before and after the interventions. According to the publisher, the tests reflect the spirit of the NCTM standards (NCTM, 2000). The ITBS computation subtest tests require operations with whole numbers, fractions, decimals, and combinations of these. The problem-solving subtest includes word problems that require one or more steps to solve. Several items present tables and graphs of data that students must interpret to compare quantities and determine relationships. The subtests were administered according to the directions in the test administration booklet. Students were allowed to use calculators for the problem-solving tests only.

Implementation Fidelity

Several strategies helped to assure that EAI was implemented as intended. First, as stated above, the teachers participated in a 2-day workshop on appropriate ways to incorporate instructional technology in their classrooms, specifically, on how to teach *Kim's Komet* and the applied problem. Teachers were provided with a *Kim's Komet* instructional manual, which included lesson guides and specific suggestions for instruction. Second, the teachers described their classroom activities and the reactions of their students to them in an online teacher logbook. The research staff monitored these entries closely and answered questions as they arose. Third, an observer with considerable training in the use of EAI observed 20 percent of the classes. Finally, at the conclusion of the study, the teachers were interviewed about their experiences. The logbook entries, observer field notes, and interview responses showed that teachers implemented EAI as planned although some inconsistencies were reported in the number of days teachers spent in the multimedia instruction versus the applied problems. These differences were not judged to be serious threats to the fidelity of EAI implementation.

RESULTS

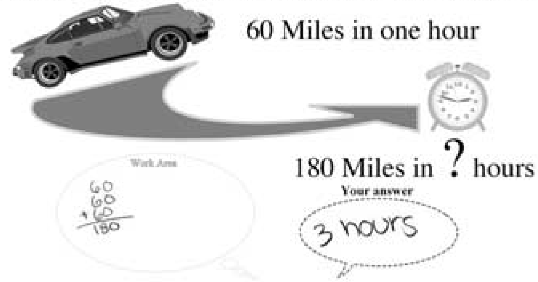
Experimental Findings

The means and standard deviations of students on the *KKPST* (waves 1–3) and standardized tests (pre, post) in each teaching sequence are reported in Table 2. Figure 4 shows the students' *KKPST* scores for each teaching sequence and test wave along with pretest and posttest mean scores of students with LD in an inclusive math classroom from a similar study. Note that the testing sequence was pre-postmaintenance for students in sequence A and pre pre–post for students in sequence B.

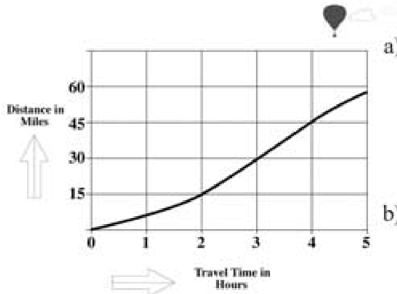
Performance on the KKPST

A two-way multivariate repeated measures ANOVA was conducted on the *KKPST* scores. The repeated factor was test wave (O_1 vs. O_2 vs. O_3) and the between-students factor was type of instruction (Typical vs. EAI). Results indicated that the main effect for test wave, $F(2, 128) = 64.43$, $p < .001$, $\eta^2 = .50$, and the test wave-by-instruction interaction, $F(2, 128) = 33.32$, $p < .001$, $\eta^2 = .34$, were statistically significant but that the main effect for type of instruction was not, $F(1, 64) = 0.81$, $p = .37$, $\eta^2 = .01$. This last result was not unexpected because the test means are averaged across all three of the test waves. In the next phase of the analysis, described

Item 1 If Bill drove 60 miles in one hour, how long would it take him to drive 180 miles?



Item 3 The following graph shows how far Ann can travel in a hot air balloon.



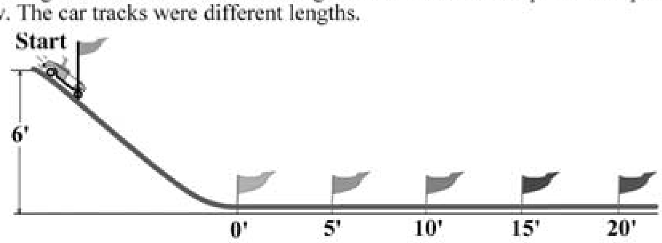
a) How much time would it take Ann to go 45 miles?

Your answer: 4 hours

b) How many miles would Ann be able to travel in 2 hours?

Your answer: 15

Item 5 Two groups of high school students were racing their cars down a ramp. The ramp is shown below. The car tracks were different lengths.



a. Calculate the speeds of the Lodi and Sun Prairie cars. Write the speeds in the tables below.

LODI STUDENTS

STUDENT	LENGTH OF TRACK	TIME	SPEED (Your answer)
Ann	10 feet	1.6 seconds	6.25 ft/s
Mary	10 feet	2.0 seconds	5 ft/s
Rich	10 feet	2.8 seconds	3.57 ft/s

SUN PRAIRIE STUDENTS

STUDENT	LENGTH OF TRACK	TIME	SPEED (Your answer)
Tom	15 feet	2.5 seconds	6 ft/s
Jan	15 feet	2.0 seconds	7.5 ft/s
Dave	15 feet	3.2 seconds	4.68 ft/s

b. Who has the fastest car in Lodi? Your answer: Ann

c. Who has the fastest car in Sun Prairie? Your answer: Jan

d. In Lodi and Sun Prairie, who has the fastest car? Your answer: Jan

e. In Lodi and Sun Prairie, who has the slowest car? Your answer: Rich

FIGURE 2 *KKPST* items #1, #3, and #5.

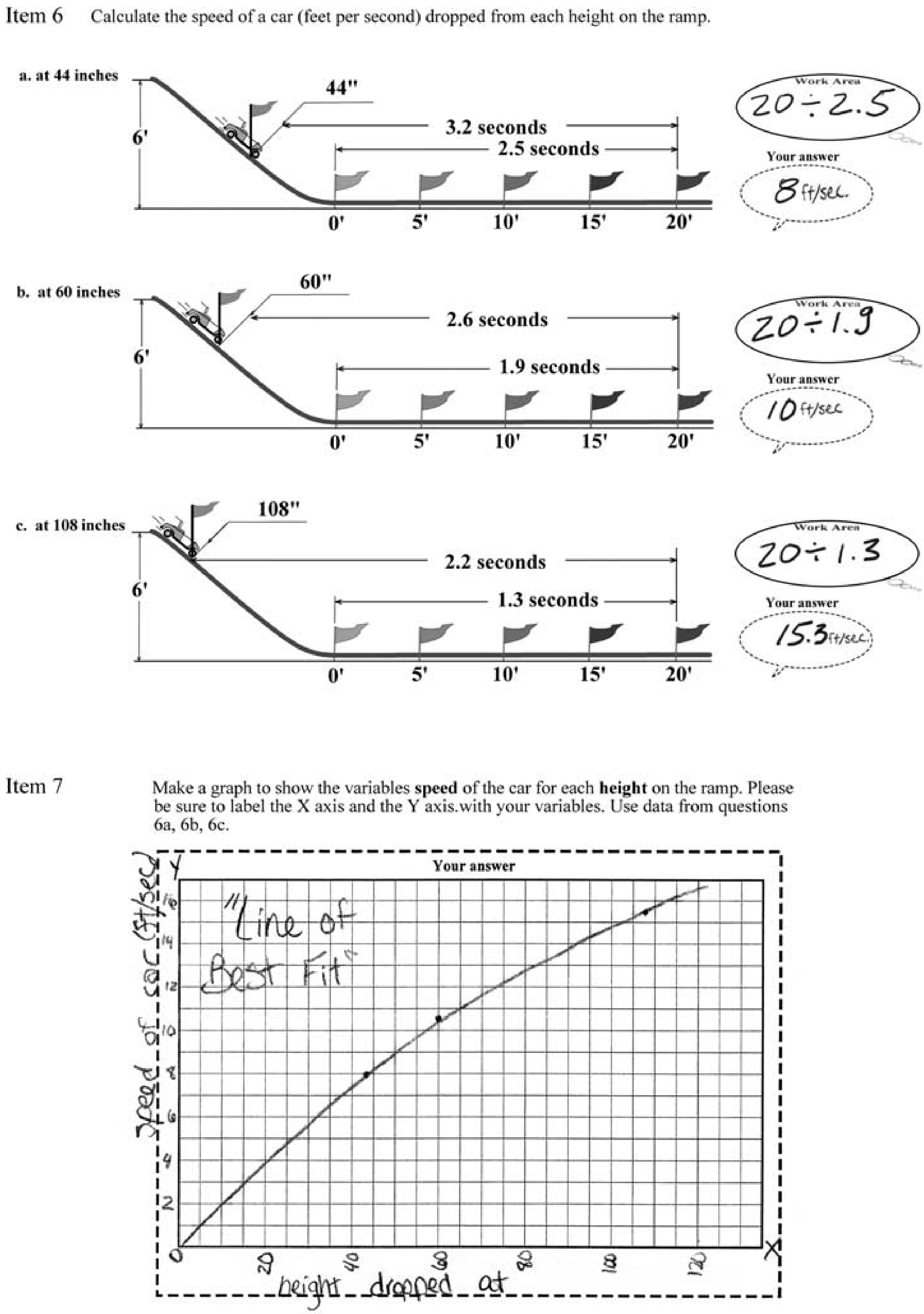


FIGURE 3 *KKPST* items #6 and #7.

TABLE 2
Means and Standard Deviations of Students by Instructional Sequence

	Sequence A			Sequence B		
Measure	*n*	*M*	*SD*	*n*	*M*	*SD*
Kim's Komet Problem Solving Test (KKPST)						
Testing 1	48	4.21	3.92	41	4.49	3.07
Testing 2	48	14.17	7.31	42	7.21	6.08
Testing 3	31	10.00	8.33	42	16.62	5.86
Iowa Tests of Basic Skills (ITBS)						
Math Computation						
Pretest	38	187	16.45	42	192	19.25
Posttest	38	192	18.00	42	207	23.35
Math Problem Solving and Data Interpretation						
Pretest	38	188	20.17	42	195	28.02
Posttest	38	197	32.25	42	207	29.26

Note. Data shown in the table are of students whose scores were included in the pairwise comparisons. Some students were not available for all three KKPST waves. Posthoc comparisons showed no differences between students included in the analyses and those of the total group.

previously as essentially a pretest–posttest control group design, it was found that the mean scores of EAI students increased significantly more than those of students in the control classrooms from O_1 to O_2 ($t = 5.08, p < .001$, Cohen's $d = 1.08$). In the second phase, a contrast test was conducted to assess whether EAI students remembered what they learned (O_1 vs. O_3). Results showed that the 31 students having both O_3 and O_1 scores had a higher mean on O_3 (10.00) than on O_1 (3.42), ($t = 5.51, p < .001, d = 0.99$). Finally, in the third phase, the scores of control students were compared for O_2 (pretest) to O_3 (posttest), in effect a replication of the first phase analysis. Results showed students scored higher on O_3 than on O_2, ($t = 9.17, p < .001, d = 1.42$). These effect sizes are considered large by some authors (e.g., Cohen, 1977) and are in line with those obtained in recent studies using EAI with high school students with emotional and behavioral disabilities (Bottge, Rueda, & Skivington, 2006) and middle school students with LD included in a general education math class (Bottge, Rueda, Serlin, Hung, & Kwon, in press).

Inspection of the individual item performances before and after EAI revealed the concepts on which students made the most improvement and those that were particularly difficult. The scores of students were collapsed across groups because they showed similar achievement patterns. Following EAI, 67 percent of the students could solve a one-step word problem (item #1) and 74 percent could read a simple line graph (item #3). In addition, over three-fourths (76 percent) of students could calculate speeds (in feet per second) when time and distance were provided and answer a series of questions about the slowest and fastest cars. Much less impressive were performances on the final set of items that required students to calculate speeds from a series of figures, label the x- and y-axis of a graph, plot their data points, and draw a line of best fit (items 6 and 7). Although almost all students received some points for this combination of items, only 33 percent of the students could do most of the operations correctly.

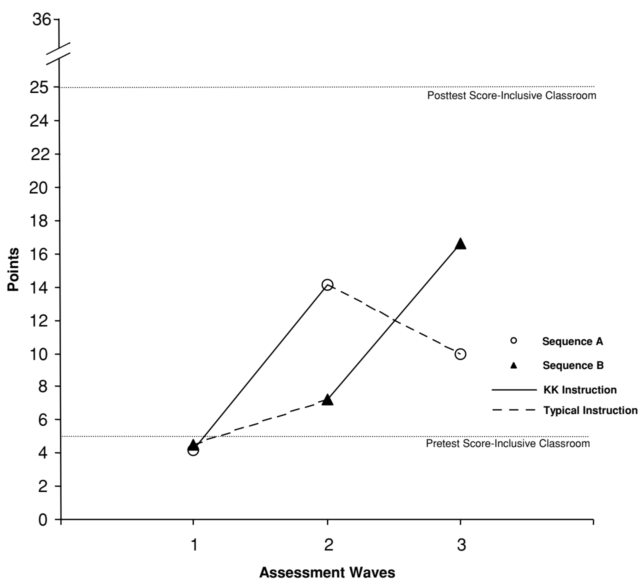


FIGURE 4 *KKPST* pretest and posttest scores for instructional sequence A and B.

Performance on the ITBS

Two separate two-way ANOVAs with repeated measures were conducted on the ITBS subtests. The repeated analyses allowed possible baseline differences to be taken into account. Time of test (pre, post) was the within-student factor and sequence group (A or B) was the between-group factor. On the Math Computation subtest, results indicated a main effect for time of test, $F(1, 78) = 21.66, p < .001, \eta^2 = .28$, for group, $F(1, 78) = 7.04, p = .010, \eta^2 = .08$, and for time of test by group interaction, $F(1, 78) = 6.26, p = .014, \eta^2 = .07$. Mean score differences indicated that, overall, students performed better at posttest (199.64) than at pretest (189.76), ($t = 4.65$, $p < .001, d = .74$), and results between groups show a larger improvement for students who were in sequence B ($M_{imp} = 15.40$) compared to students in sequence A ($M_{imp} = 5.06$), ($t = 2.50, p < .015, d = .56$). On the ITBS Math Problem Solving and Data Interpretation subtest, results showed a main effect for time of test, $F(1, 78) = 12.81, p = .001, \eta^2 = .14$, but not for group, $F(1, 78) = 2.47, p = .12, \eta^2 = .03$, or for time of test by group sequence interaction, $F(1, 78) = .16$, $p = .69, \eta^2 = .002$. Mean score differences indicated that, overall, students performed better at posttest (202.51) than at pretest (191.56), ($t = 3.58, p < .001, d = .57$).

Explanatory Findings

Two key themes were identified from the data sources to help explain the quantitative findings. The first theme related to the tenacity teachers showed in teaching higher order problem solving to their students who had long histories of low achievement in mathematics. Teachers reported their frustrations when lessons did not proceed as planned and their surprise when students went beyond what they had expected. The second theme related to the effort their students showed as they worked to unravel the complexities of the video-based and applied problems. Because of the obvious relationship between the themes, they are described collectively rather than as separate entities.

Teachers detailed the difficulty their students faced learning the two most important concepts embedded in *Kim's Komet*: Figuring out the relationship between time, distance, and speed and using graphs to represent this relationship. For example, students had to accurately time their cars on the straightaway from several release points (i.e., heights) on the ramp. From these data, they could compute the speed of their cars from each release point. Knowing the release points and speeds, they could then plot them as ordered pairs, draw a line of best fit, and use their graph to estimate the speed of their cars released from any height on the ramp. Thus, the speed of their cars (x-axis) as they entered the tricks at the end of the straightaway was a function of the release point on the ramp (y-axis). After they had timed their cars, calculated speeds, and made their graphs, teachers revealed to students the range of speeds within which their cars could successfully navigate each trick.

Teachers thought that their students' prior knowledge was especially important in helping them understand these concepts. For example, after watching the *Kim's Komet* video, a teacher described how one of her students related what she had learned in science class to the problem shown in the video:

> One girl was right on how the pentathlon worked. She predicted that a car that starts lower on the ramp will go slower than a car that starts out higher on the ramp. Additionally, she figured out that we are using a line graph because that is the only one that would make sense to mark speed and time on (she came up with those ideas herself). She may have remembered that stuff from science. However, they covered that like 3 months ago, but you never know.

Teachers also reported that several of their students had difficulty, at first, noticing how variables were related, how they should construct their graph and draw the line of best fit, and how the graph could help them solve the overarching problem. For example, one teacher wrote:

> Most students want to connect the dots. After having them do line graphs they graphed averages to *Kim's Komet Smart Tool* (graph). They did not understand the relationship between variables. Many still drew a straight line. We then discussed what was happening with the speed and how the smart tool is actually an acceleration [deceleration] curve.

The next day, the same teacher remarked:

> Students finally making some connection to applied part of problem. Several were actually saying "Oh, I get it. The graph helps me know where to drop [release] the car." It may take a day or two for some to still make the connection. Finally [they] understand x,y intercept. Appear to be using graph correctly. Students are more excited about project now that we've had some experience using the graph with the video.

This turnaround in students' understanding from 1 day to the next was common for all the teachers. One student, referring to a common misunderstanding that the fastest car and not the most accurate graph would win the contest, exclaimed: "Being fast sure didn't help me, Miss!"

Teachers commented on how motivating the problems were for their students although the level of engagement varied. One teacher was surprised that her class, which was usually disruptive just before Winter break, was the most involved at this time. The teacher remarked: "Well, the kids who are normally disruptive are up to their normal selves. However, everyone finished their work! It was amazing!" One teacher summed up her thoughts about the day the pentathlon was held in her class: "For the majority of kids it was a dream of a day, excited and exciting. For a few it was hell on wheels. . . as it were." Two of the teachers reported that students from other classes in the school attended the pentathalon. One teacher wrote:

> We have folks from all over the building dropping by the stage area to investigate and cheer the kids on. It was delightful and oh so good for them. We have a couple of 7th graders who are already planning for next year!

This engagement even carried over into test taking. The teacher wrote that one student who was taking the KKPST posttest informed her that her shoes (heels) made too much noise, which affected his concentration. He politely asked her to stop walking around the classroom. Commenting on test day, the teacher wrote:

> I know this sounds bizarre, but they were smiling as they took the test. Even the questions they asked were real math questions and generally didn't even need an answer. As they voiced the question they figured out how to get an answer. Whether or not they do well on the test, their individual level of confidence has risen to the sunshine!

Teachers also noted that instruction with the multimedia component of EAI resulted in only partial understanding of the math concepts. For example during the first days of instruction with Kim's Komet, one teacher commented:

> They all participated in class discussion. One kid was a little lost sometimes because he was not paying attention. However, the same kid also first identified that you couldn't compare Darlene's and Kim's cars (main characters in the video) because their tracks were different lengths. One kid suggested that Darlene cheated and used a shorter track.

It was not until students had the opportunity to apply what they were learned in the video did the reasons for testing their cars from various heights on the ramp and graphing their data become clear. As one teacher described it:

> Again, I am reminded of the difficulty of very "concrete" students transferring information to a more abstract area. And,

of their difficulty in learning a concept, then seeing it in a different format. . . not even a difficult format, just different.

DISCUSSION

A mixed methods approach was used to test and describe the effects of EAI on the math performance of students with MLD in special education settings. Findings from the quasi-experimental study suggested that students with MLD profited from EAI and, despite some degradation in performance over time, they retained much of what they had been taught several weeks before. The growth pattern shown in the first instructional sequence was replicated in the second sequence. Item performances revealed that most students could interpret line graphs and calculate speeds when distance and time were known. Students had most difficulty in analyzing and graphing the data from figures displayed on the test. On the standardized measures, posttest scores showed improvement on the problem-solving test for both groups while results were mixed on the computation test.

As in our previous research with EAI, elements of a theoretical model (Bottge, 2001) for teaching mathematics to low-achieving students were evident. For example, teachers wrote numerous entries commenting on students' motivation as they worked on the problems in *Kim's Komet*. Although some entries described students' periodic *lack* of engagement, teachers most often wrote about their students' genuine interest in solving the problems, a prerequisite several authors have identified as necessary for developing deep understanding (Bransford et al., 2000; Bruner, 1960; Dewey, 1938; Schoenfeld, 1989; Wertheimer, 1959). In particular, students showed interest when they got the chance to test their cars and compete in their own class pentathalon. This level of excitement contrasts sharply to the disinterest many students show in solving word problems (Brown et al., 1989; Lave, 1993).

Of course, engagement by itself does not guarantee that students will learn anything substantive. Careful consideration must also be given to what a specific unit of curriculum contains (and does not contain), how it is organized, and the integrity with which it can be implemented. Much of the curriculum and teaching methods used with low-achieving students is highly procedural with learning tasks broken down into small, sequential chunks (e.g., Carnine, 1997; Carnine, 1998). The theoretical base for chunking curricular content is related, in part, to a theoretical construct called cognitive load theory (CLT). In its simplest form, CLT suggests that all learners have limited working memory and that learning tasks should be structured in ways that do not overload it.

However, recent investigations of CLT have revealed much more complex interactions between the structure of information to be learned and cognitive processing needed for understanding (Paas, Renkl, & Sweller, 2003). One consideration has to do with element interactivity, or the extent to which relevant elements interact. In learning low element interactivity material, each item can be understood without reference to other items. High interactivity materials can also be learned as individual units, but they cannot be fully understood until all the elements are processed simultaneously. To reduce the cognitive load imposed by the complexity of high interactivity problems, scaffolds either prior to or during the learning task (i.e., devices or strategies that support learning) are used to guide the learner to the desired goal (van Merienboer, Kirschner, & Kester, 2003). Story contexts, visual representations, and ongoing cognitive supports have been shown to enhance learning (Mousavi, Low, & Sweller, 1995; Rittle-Johnson & Koedinger, 2005). Multimedia applications have been especially helpful in delivering these supports (Mayer & Moreno, 2003; Tabbers, Martens, & van Merrienboer, 2004).

Because *Kim's Komet*, like other problem-based curricula, would most likely be situated at the high end of the interactivity continuum, several cognitive supports needed to be embedded in the learning materials in order for students to understand each subproblem. For example, in the multimedia environment, students could time the cars of the students shown in the video, replay it as often as they wished, and revise their graphs as needed. On the applied problem, students timed their own cars, made their own graphs, and participated in the class competition. Students also observed the work of others, which provided them with models of how to construct their graphs. Teachers provided additional support by providing just-in-time instruction on the concepts that students had particular difficulty learning (e.g., time–speed–distance relationship, plotting variables). These opportunities for student interactivity helped to reduce the cognitive load imposed by the complexity of *Kim's Komet* and the pentathlon competition.

As for the elevated standardized computation test scores, they are encouraging but should be viewed with caution. Because the design of the study included periods of typical instruction, we cannot be sure how much of this improvement, if any, can be attributed to EAI. Although there has been some evidence to suggest computation instruction embedded in EAI may have important benefits (e.g., Bottge, Heinrichs, Chan, Mehta, & Watson, 2003; Cohen, Bottge, & Wells, 2001), it is not possible to disentangle the instruction-by-performance effects in this study. All that can be stated with cautious optimism is that some students in both sequences improved their computation scores by participating in the combination of EAI and typical curricula.

Although the results of this study were positive overall, the conclusions that can be drawn from it are somewhat limited. First, students in both groups showed consistently higher posttest scores on the curriculum-aligned measure, but their scores were about 8 to 10 points lower than those of students with LD obtained in a recent study conducted in a general education math classroom (Bottge et al., 2006). These differences are most likely due to both teacher and student factors. One teacher factor may be the level of the special education teachers' mathematical knowledge. For example, Maccini & Gagnon (2006) found that special education teachers at the secondary level reported having less formal knowledge of mathematics than math teachers. In general education, achievement gains of students have also been linked to the mathematical knowledge of their math teachers (Hill, Rowan, & Ball, 2005). Although the special education teachers received training on teaching the EAI problems, they may have needed additional practice to teach EAI more effectively.

Second, the skills of the students with MLD were much lower than those of students with MLD in our previous research, and their background knowledge may have been too limited to acquire full understanding of the math concepts. Students in this study came from more diverse backgrounds (e.g., English as a Second Language), were likely to have identified disabilities in more than one area (e.g., reading, written language), and received large amounts of special education services. The results suggest that more scaffolding and more practice are needed to help students understand the relationships between data collection, data interpretation, and graph construction.

Finally, the *KKPST* may not have tapped all of the students' understanding of the concepts embedded in the EAI problems. The teachers thought their students had learned more math skills and concepts than they were able to show on the posttests. This issue relates to the mismatch between instruction and assessment formats. Although the test was designed to assess knowledge of the concepts in *Kim's Komet*, the figures and diagrams used in the test are static and only approximations to the way they appeared in the instructional contexts. Thus, students may have been confused by contextual differences in the test questions, which could have contributed to the decline in scores of sequence A students from posttest 2 to maintenance test 3.

Despite these limitations, this study uncovered ways that students with MLD could participate in the kinds of learning activities consistent with those emphasized in current math reform. Although their computation skills were low, students learned relatively complex concepts, which in many cases far exceeded teacher expectations. This finding suggests that teaching concepts for understanding does not always have to wait until all related procedural skills (e.g., algorithms) are mastered (Goldman, Hasselbring, & The Cognition & Technology Group at Vanderbilt, 1998; Hickey, Moore, & Pellegrino, 2001).

To be sure, these findings contribute but one data point to the debate over what elements of math reform are appropriate for students with MLD. This study has shown that special education teachers can be effective in teaching their students with MLD in self-contained settings in ways that are consistent with the NCTM standards. Both the numerical and qualitative results revealed, however, that to teach and learn this way require considerable training on the part of teachers and close attention to the way instructional materials are structured.

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