Enhancing Mathematics Achievement

Building Ramps and Hovercrafts—and Improving Math Skills

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How can students with disabilities meet challenging standards in the content areas when many of these students have difficulties with reading? (see box, "What Does the Literature Say?") This is the challenge we faced as we worked with students to use real-life problems to overcome this barrier.

This article describes a video- and computer-based program that can motivate youngsters with disabilities to learn math concepts.

Background: Bart

Ten years ago, my colleagues and I attempted to bypass the reading roadblock by developing an 8-minute video called *Bart's Pet Project,* which involves two middle school students who want to buy a pet and a cage to put it in. The Bart video is based on the principles similar to those used in developing the *Adventures of Jasper Woodbury* by the Cognition and Technology Group at Vanderbilt (CTGV, 1997). Like the Jasper adventures, the Bart video is presented on videodisc, which enables students to search the video quickly to retrieve the relevant information embedded in the story.

NCTM 2000: All students should have the opportunity to solve meaningful and complex math problems.

To solve the Bart problem, students have to figure out how to use several lengths of 2 x 2-inch-dimension lumber in the most economical way to build the cage frame. Students gain practice in adding and comparing mixed numbers because the cage dimensions are in mixed numbers. After students show how to cut the lengths of wood in the most economical way, they then must decide whether they have enough money to build the cage and buy one of the pets in the store. Results of an experimental study indicated that students who learned how to solve the video-based problem could transfer what they learned to a similar but different task (i.e., kite frame problem), unlike students who were taught the same concepts using word problems (Bottge & Hasselbring, 1993).

An interesting aside to the study involved a student who had received special education services for many years who found a third solution to the problem after the developers of the video thought there were only two.

An Experiment in Authentic Problems

In a more recent study with middle school students employing mixed research designs (i.e., experimental and quasi-experimental) involving math, special education, and technical education teachers, we obtained similar results (Bottge, 1999). The addition of the technology education teacher to the team was a fortunate occurrence—but unplanned.

One day I casually asked him if he knew of "authentic" ways to test students' ability to transfer what they learned in the video. He seemed surprised and puzzled by my question. When I asked him why, he replied, "In my 25 years of teaching technology education, no one from the 'academic' wing ever asked me for help, unless it was for help fixing something."

I showed him plans of skateboard ramps I had obtained from several Web sites and a local skateboarding store. I asked him to modify the designs to create an authentic way of using 2 x 4-inch-dimension lumber to build the ramp frame. When I returned to his "shop" the next day, he showed me a schematic plan of a 7-foot-long skateboard ramp with top, end, and side

Instruction to facilitate and improve problem-solving among students with math disabilities must better reflect its meaning and purpose out of school.

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views. He also created an assessment that could measure students' skills in figuring out the most economical way to cut two by fours.

Results of this study showed that students in remedial math class who learned to solve the Bart problem were much quicker at solving the ramp problem than were students in the word problem group. After the students figured out where to cut the two by fours, they used their plans to build two large ramps, which they tried out later in the school parking lot. Effect sizes, which are standardized measures of the difference between the experimental and comparison groups, on the problem-solving posttest measure were .56 and .50 in the 1993 and 1999 studies, respectively. Effect sizes on the transfer task were .37 in both studies. According to J. Cohen (1977), an effect size of .30 is a medium effect and .50 is a large effect.

The middle school principal, who had kept a close eye on the research findings, decided to modify the schedule to give the math, special education, and technology education teachers time to plan and implement an integrated math curriculum for low-achieving math students the following year. The schedule made it possible for all three teachers to take active roles in teaching the math curriculum in a remedial math classroom. Instead of building skateboard ramps, the eighth-grade students planned and constructed two large compost bins that were needed at the new high school. The names of the students were engraved on plaques attached to the bins, which are now in use at the school.

Case Description—Chad

Chad participated in the study that linked the use of *Bart's Pet Project* in the math classroom to building a compost bin in the technology education classroom. One purpose of the study was to track the performance of students on computation and word problems as they worked on contextualized problems (i.e., video and applied problems). Results of the study showed that some students improved their performances on short tests of computation and text-based problems despite having received no direct teaching on how to solve them (see Cohen, Bottge, & Wells, in press).

Chad was diagnosed with learning disabilities in the second grade and received resource and consultative services 300 minutes a day. According to his special education teacher, he had severe reading difficulties that hampered his progress in all content areas. During typical instruction in the days before the study, Chad was uncooperative and refused to work. The math teacher described his behavior as "rude, disrespectful, obstinate, and sitting upside down in his chair." She tried to con-

What Does the Literature Say About Achieving Higher Standards in Math?

The recent movement toward higher standards and the emphasis on tests to measure them can be traced to *A Nation at Risk,* published almost 20 years ago (National Commission on Excellence in Education, 1983). Since then, business leaders and government officials have put pressure on teachers and administrators to raise achievement in all content areas, especially reading and mathematics (e.g., *Goals 2000: Educate America Act,* 1994; *What Work Requires of Schools: A SCANS Report for America 2000*, U.S. Department of Labor, 1991).

In mathematics, revised standards of the National Council of Teachers of Mathematics (NCTM, 2000) emphasize giving *all* students the opportunity to solve meaningful and complex math problems. In grades 6-8, this means

> Young adolescents should regularly engage in thoughtful activity tied to their emerging capabilities of finding and imposing structure, conjecturing and verifying, thinking hypothetically, comprehending cause and effect, and abstracting and generalizing. (p. 211)

Students with Disabilities and Standards. The trend toward higher standards is also indicated in the reauthorization of the Individuals with Disabilities Education Act (IDEA) Amendments (1997), which promotes opportunities for students with disabilities to learn challenging curriculum alongside their peers without disabilities.

Teaching and Learning Complex Math Problems. Progress in meeting these goals with students with disabilities is limited for several reasons, including the lack of collaboration between special education and mathematics teachers (Cawley, Parmar, Foley, Salmon, & Roy, 2001). The most serious problem, however, may rest in the way textbook publishers and test developers have defined problem-solving, that is, with text-based problems commonly called *word problems.* Although important research has helped teachers improve student performance on word problems using methods such as direct instruction (Carnine, 1997) and metacognitive strategies (Montague, 1997), cognitive scientists define a problem in quite a different way. For much of the past century, authors have labeled situations as "problems" only when they evoke in individuals a genuine interest in obtaining a solution (Bruner, 1960; Schoenfeld, 1989). Word problems seldom cause this type of reaction in students with disabilities, especially with students who cannot visualize or comprehend problem situations because of poor reading skills.

The importance of defining the nature of a problem affects both teaching and learning. For example, in a study of more than 1,500 schools, Newmann, Secada, and Wehlage (1995) concluded that higher student achievement resulted when instruction was more authentic and focused on (a) construction of knowledge, (b) disciplined inquiry, and (c) value beyond school.

Finding ways to deliver meaningful and motivating problems to students with math disabilities is a formidable challenge because many of them are also poor readers.

vince Chad that he would improve his math skills by participating in the study and watching the video. Chad shouted out loudly that the video was dumb (although he had not yet viewed it) and added that he "used to like math, but not now." He explained that he learned math better by doing worksheets and that watching a math video was a stupid idea.

Despite his initial reactions, Chad's behavior improved significantly during video instruction. He sat directly in front of the television monitor, attentive to what was happening in the video. The second day, his behavior was inconsistent. He searched for facts in the video over a long period. The next day Chad displayed "outstanding behavior" during the entire class period. When other students were off task, he was attentive and searched the video with the videodisc controller. Eventually he joined three students and together they solved the problem.

In the technology education classroom, Chad participated fully in solving the bin problem and then constructing it. He worked closely with his partner and even helped other students when they had questions about how to proceed.

In the post-study interview, Chad said: "At first I thought the video was dumb, but then I started to understand the problem." He explained that he liked the idea of watching the video several times because he could figure out what information he needed to solve the problem. He added that "instead of just listening to the teacher explain something, you can visualize it and see what is going on." When he was asked about his success in solving the video and applied problems, he stated:

> I thought it was easier 'cause I got to handle the wood. That helped me and I got to put it together, but on the worksheets you just keep thinking, you can't visualize it, you don't have a ruler, and you are not measuring or anything.

In my 25 years of teaching, no one from the "academic" wing has ever asked for help [with curriculum].

—Technology education teacher

At first, I thought the video was dumb, but then I started to understand the problem.

—Chad

More Challenging Problems

Encouraged by these findings, we conducted a study the next year with eighth-grade students (Bottge, Heinrichs, Chan, & Serlin, in press) using a more difficult problem called "Kim's Komet" from one of the *Adventures of Jasper Woodbury.* The video asks students to measure and predict where on a ramp they should release their model cars to negotiate several stunts such as short and long jumps to achieve the speed at the end of a straightaway. Because the cars could successfully complete a stunt within a range of speeds, it was important for the students to accurately calculate where on the ramp to release their cars. Students gained practice in figuring out speeds for several heights on the ramp. They also learned how to predict speeds of other heights on the ramp by drawing a "line of best fit" that represented all the data points on their graphs.

After students solved "Kim's Komet," they went to the technology education classroom to apply what they learned using the ramp and stunts (e.g., short jump, long jump) that the teacher constructed. Students made their own cars and calculated their speeds at the end of the straightaway after releasing them from several heights on the ramp. They graphed their data and then competed in their own derby the next day. Results of the study were surprising. Students in the remedial math class did not differ significantly in performance on posttests and maintenance tests from students in prealgebra classes who received the same method or traditional methods of instruction on these concepts.

Case Description—Dan

Dan's individualized education program (IEP) indicated that he received 5 hours of special education service a day in reading, written language, and mathematics. Standardized test scores in mathematics showed his performance at the 17th national percentile on the math subtest of the Wisconsin Student Assessment System (WSAS) state math test and the 10th national percentile on the Wide Range Achievement Test (WRAT3; Wilkinson, 1993). From informal conversations with Dan during the study, he was confident that he already knew something about speed because he had raced model cars in Boy Scouts.

Evidence from the problem-solving posttest and two maintenance tests indicated that he learned how to predict speeds, read data from tables, and graph the information in a meaningful way. On the 30-point problem-solving test, Dan improved his score from 8 points on the pretest to 19 points on the posttest, which approached the average score of 20 achieved by prealgebra students. Even more impressive, he missed a perfect score on the maintenance test by only 2 points because he did not scale his graph appropriately (see Figure 1).

> At first when I had to do it all by myself, I totally didn't get it, but then after seeing and doing it a couple of times, like measuring speed and drawing it on the chart, it became a little bit easier.

He described what he learned in this way:

> You really learn something from it. Especially with the speed and cars, not only just math, but you learn how to design stuff too. I think that it is really good.

Figure 1. Dan's Table and Graph

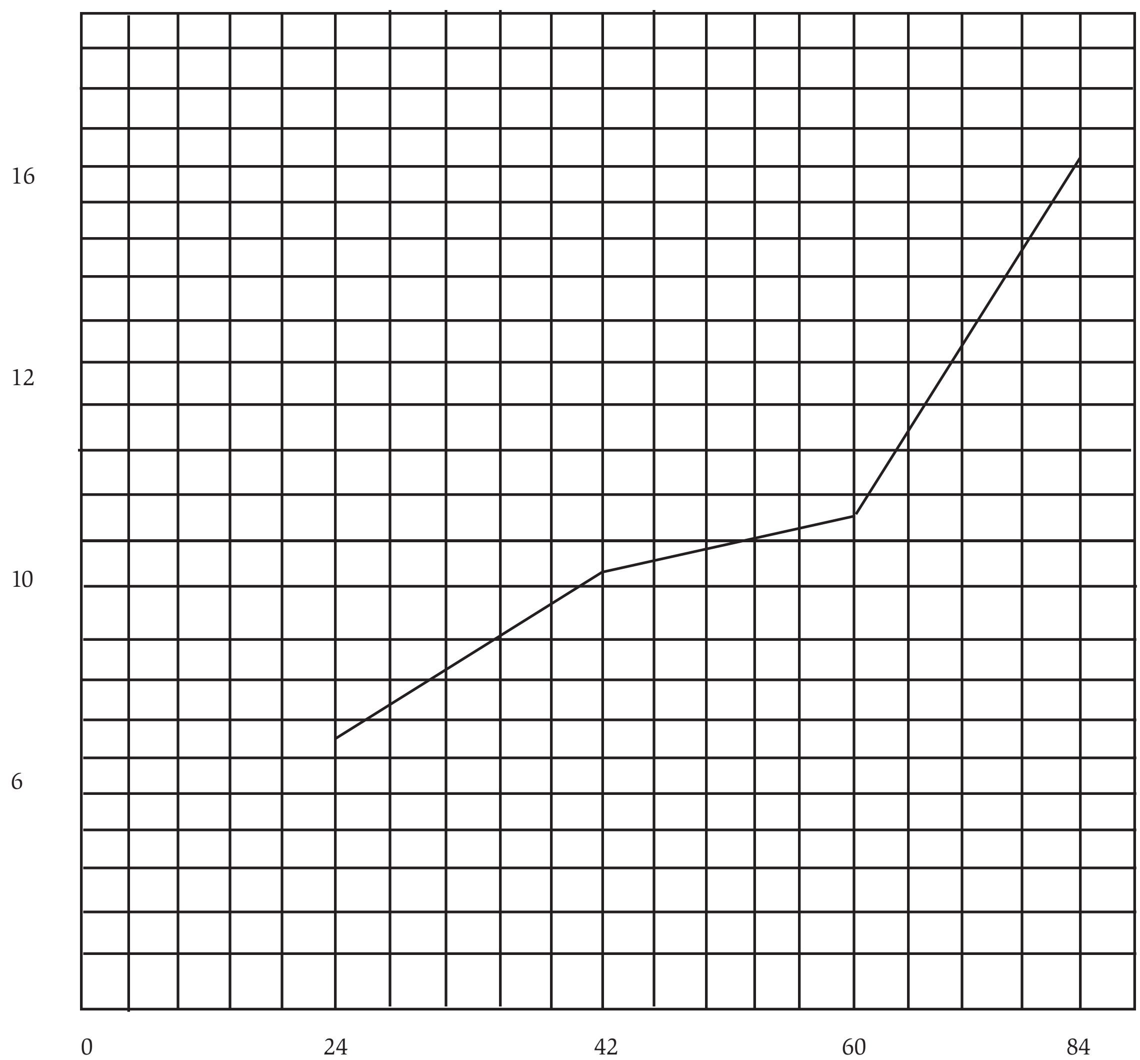
Name: *Dan*

Measure 1

1. In the table below, record both the *height* from which the car is dropped and the *time* it takes to go 5 feet. Calculate the speeds and write them in the table.

Height (inches)	Length (feet)	Time (seconds)	Speed (feet per second)
24	5 feet	.759	6.5
42	5 feet	.484	10.3
60	5 feet	.392	12.7
84	5 feet	.309	16.1

2. Now make a graph showing the *height* and *speed*. Be sure to label the x and y axis.



Ongoing Research, Development, and Replication

This year we conducted two studies to assess the performance of students with disabilities in math classrooms and resource rooms with a new video problem on a CD called *Fraction of the Cost*. Three students from a local middle school, including a girl with Down syndrome, starred in the 8-minute production that parallels the problem in *Bart's Pet Project*.

The friends in the video attempt to figure out how they can afford to build a skateboard ramp with their money

Instead of just listening to the teacher explain something, you can visualize it and see what is going on.

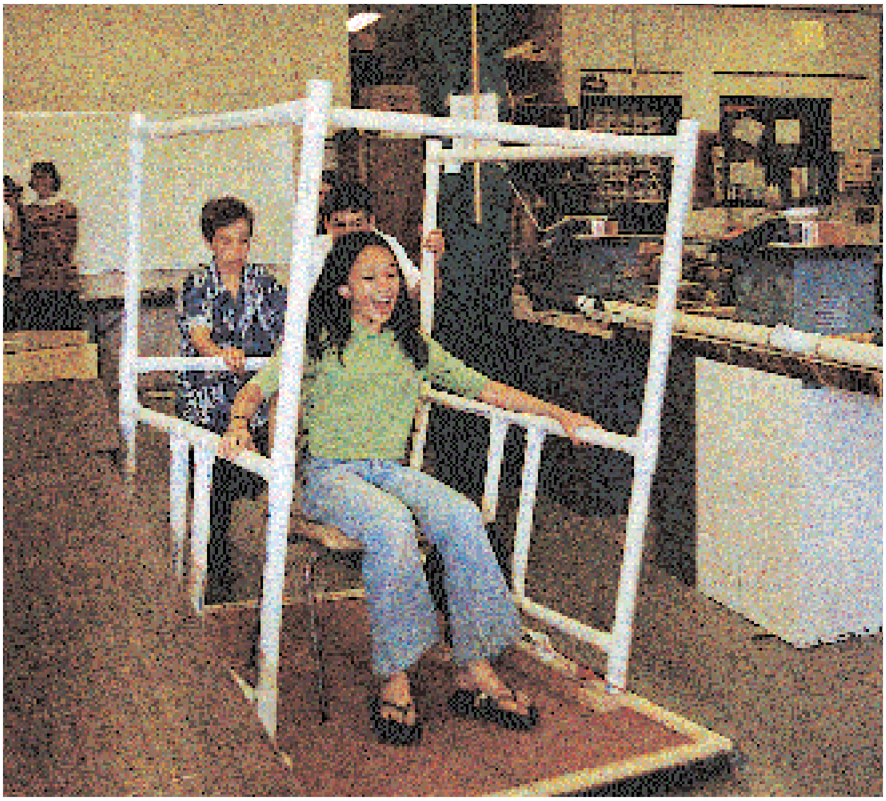
—Chad

and leftover lumber they find in one friend's garage. In addition to finding the most economical way of using the wood, students need to calculate interest in a savings account and sales tax on a purchase, convert feet and inches to inches, read schematic drawings, construct a table of materials, and compute and compare values represented as mixed fractions.

At the conclusion of the project, students applied what they learned in the video to plan, draw, and construct a "rollover cage" out of PVC pipe for a hovercraft. Each student drew a schematic plan showing several views of the cage and built a model to scale out of plastic straws (see Figure 2). Then students voted on the three designs they wanted to make. The teacher divided the class into three groups, and each group planned how they could make the cage in the most economical way, which involved cutting the 10-foot lengths of pipe wasting the least amount of pipe as possible. Students also included the cost of pipe connectors in their calculations.

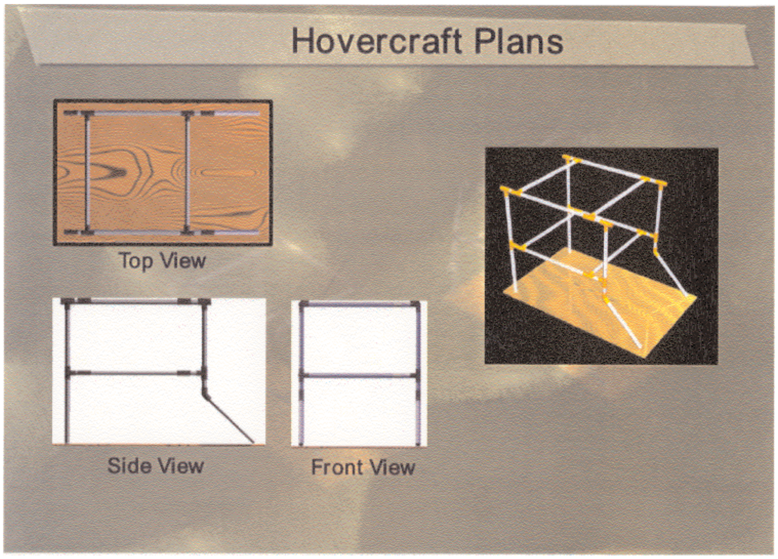
Once the teacher approved the plans, students worked on measuring, cutting, and assembling. When the cages were complete, they lifted them onto a 4 x 4-foot plywood platform (i.e., hovercraft). A leaf blower powered the hovercraft, which was inserted into a hole in the plywood, inflated the plastic attached to its underside, and elevated the hovercraft slightly above the floor. Students rode on the hovercrafts in relay races the last day of the project.

Analyses of the results of this research are not complete. Preliminary performance data and observations of



After students measure, cut, and assemble their project, they give them a try.

Figure 2. Hovercraft Frame Problem



You really learn something from it . . . not only just math, but you learn how to design stuff, too.

—Dan

students with disabilities in math classrooms so far, however, have resulted in modifications of the CD. For example, students can measure and compare lengths of wood needed to build the skateboard ramp by dragging pieces of lumber and placing them on the required lengths. Another module gives students the chance to build the ramp and take it apart again. Other additions will be made to the CD, based on follow-up interviews with students and their teachers and on research with math, special education, and technology education teachers in 15 middle schools this year.

A Few Thoughts on Assessment

One of the most controversial issues in the standards movement focuses on finding more appropriate ways to test students' performance. Most high-stakes assessments require students to read descriptions of problems in text and then to select the most appropriate answer from among several choices or supply short answers to factual questions. Because many students with disabilities in math also have difficulty reading, it is doubtful typical text-based testing formats adequately measure these students' understanding and application of problems.

To measure student performance in our studies, we have devised ways to score student work reliably, using templates based on well-defined criteria. For example, Figure 3 shows a scoring template for the video *Fraction of the Cost*. Students are asked to describe in numbers, figures, charts, and words how they would solve the problem. They receive full or partial credit for the information they provide (see Figure 3).

The principal modified the schedule to give three teachers time to plan and implement an integrated math curriculum for low-achieving math students.

Figure 3. Criteria for Scoring *Fraction of the Cost*

Money

Solution →			Partial Credit	OR	Full Credit
CINDY	$19.00		0		1
RYAN	$21.00		0		2
MICHAEL	$23.00		0		1
Each Person's Contribution or Total	$19.00 or $57.00		0		2

TOTAL Money section = 6

Materials in Garage

Solution (2" x 4" 's)		Partial Credit	OR	Full Credit
70 5/8"				
59 ¾"				
92 ¼"				
61 ¼"				
28 ¾"				
(0,1,2 correct = 0)		3 or 4 correct = 2		All Correct = 4

TOTAL Materials in Garage section = 4

Solution - # and Length of 2"x 4"'s needed for ramp frame = CONVERTED TO INCHES				Partial Credit	OR	Full Credit
# of 2"x 4"	Length (feet & inches) of 2"x 4"	INCHES				
7	3' 9"	45"				
	4' ¾"	48 ½"				
	5'	60"				
	4' 7 ¼"	55 ¼"				
2	2'	24"				
2	8 ¼"	8 ¼"				
Quantity Correct				4 or 5 correct = 2	OR	6 (all) correct = 4
		Conversion Correct		4 or 5 correct = 3		6 (all) correct = 6

TOTAL Conversion section = 10

Show Combinations for Cutting 2 x 4's

		Partial Credit		Full Credit
Shows 2 x 4's cut in some sensible way with at least one 2 x 4 shown cut in an economical way		4	OR	
Shows 2 x 4's cut or tells how 2 x 4's should be cut for COMPLETE solution 1 or 2				8

TOTAL Calculating the Solution section = 8

Solution – Total cost of all materials		Partial Credit		Full Credit
Total Cost of all materials w/out Tax ($53.79) or lists all materials		2	OR	
Total cost of all materials AND attempting Tax ($53.79 + $ 2.69)		4	OR	
Total with Tax ($ 56.48)				6

TOTAL cost of all materials section = 6

Description in Text = 2

TOTAL POINTS = 36

Where to Begin

http://www.wcer.wisc.edu/TEAM/
Provides background, teaching strategies, applications, assessment methods, and the movie *Fraction of the Cost.* It is the official Web site for the research team that is conducting the studies reported in this article.

http://peabody.vanderbilt.edu/ctrs/ltc/Research/jasper.html
Describes the *Adventures of Jasper Woodbury* including the rationale for developing the videos and instructions for using them in your classroom.

http://littleplanet.com/index.html
The Web site for Little Planet Learning, a company that develops technology-based learning programs that feature "anchored instruction."

http://www.tomsnyder.com/
Highlights a variety of software for classroom use including several related titles in math.

Teaching Recommendations

- Provide meaningful problems that build on students' prior experiences.
- Help students gain confidence by allowing them to test solutions in small groups.
- Provide opportunities for students to apply their knowledge in new and practical ways.
- Recruit teachers with special expertise to plan and deliver curriculum.
- Keep expectations for students high.
- Continue to emphasize foundation skills (computation, text-based problems).

Theory as Guide

The activities described in this article are rooted in a rich history of teaching and learning theory, grounded in cognitive science and summarized in the Key Model of learning mathematics (Bottge, 2001). Briefly, the model suggests that instruction to facilitate and improve problem-solving among students with math disabilities must better reflect its meaning and purpose out of school. That is, instruction should afford students opportunities to solve meaningful problems in contexts that make use of their prior informal learning experiences in an atmosphere of "safe" groups where they can try out their plans before revealing them in high-stakes settings. The emphasis on authentic learning experiences, however, does not lessen the need for explicit instruction on basic facts and computation. When students understand that quick and accurate retrieval of basic math will help them solve problems they care about, they may become more motivated to learn the basics.

Basing instruction on new perspectives of problem-solving could have a profound effect on the way students with disabilities learn and are assessed in mathematics. For example, suppose all students were taught and tested with problems that did not involve written text. That change, by itself, would help ease the difficulty that many students have in reading and comprehending text in word problems (Jitendra, Hoff, & Beck 1999; Xin & Jitendra, 1999).

Just the Beginning

Our research team has witnessed many "surprises" when students receiving special education services for many years could solve problems in much the same ways as students without disabilities. We still have much to learn about the teacher and student factors that produced these results. More research will help discover which of them may be critical in helping students with disabilities show us what they really know.

Teachers can begin exploring video-based and applied problems on several Web sites (see boxes, "Where to Begin" and "Teaching Recommendations"). For example, the http://www.wcer.wisc.edu/TEAM/ Web site allows users to watch *Fraction of the Cost* and access several of the help modules. Teachers can use a computer and projector to show the video in the classroom. Students can search the video for the relevant information on the video and use the resource modules to help them solve the problem in much the same way as using the CD version. Teachers can also assess their students' performance by using the scoring guides. Information about how to begin teaching with the video and applied problems can be obtained by sending an email to TEAM@education.wisc.edu.

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