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Advancing the Math Skills of Middle School Students in Technology Education Classrooms

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Abstract

While curriculum specialists and committees often decide how mathematics is taught, it is ultimately principals who influence the extent to which these initiatives are carried out. The overall goal of this article is to provide school leaders with classroom-based research that describes one way of improving the math skills of middle school students. The study employed a randomized pretest-posttest comparison group design to examine the effects of two versions of Enhanced Anchored Instruction (EAI) and a Business as Usual (BAU) condition on the math skills of middle school students in technology education classrooms. Results showed that both EAI conditions were effective at improving the math skills of students over those of students in the BAU classes. The findings suggest that technology education teachers can make important contributions in helping students develop their computation and problem-solving skills.

Keywords

math, technology education, middle school, anchored instruction

Although recent results of the National Assessment of Educational Progress (Lee, Grigg, & Dion, 2007) showed improvement in mathematics for students at all achievement levels, 26% of students without disabilities and 67% of students with disabilities in Grade 8 still scored below the *Basic* level in math. To reach the achieve

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Basic level, students must be able to use structural prompts such as diagrams, charts, and graphs to solve problems. They should also be able to solve problems with the help of technological tools, such as computers and calculators. These skills are consistent with requisite skills for new jobs (e.g., National Center on Education and the Economy, 2007).

Controversy over what and how math content should be taught in K-12 classrooms has raged on over the past two decades (see Schoenfeld, 2004). Most educators would agree on the need for developing curricula and teaching strategies that foster growth across a range of competencies, but important questions still remain about what mathematics knowledge is worth learning (Roschelle, Singleton, Sabelli, Pea, & Bransford, 2008) and the nature of learning activities that would promote this knowledge (Greeno & Collins, 2008).

The central instructional issue is how to deliver engaging instruction that values procedural fluency (e.g., computing with fractions) while also giving attention to conceptual understanding (e.g., the meaning behind computational rules). Most teaching strategies are located somewhere on a continuum from leading students through a series of prescribed procedural steps to asking students to figure out the solutions to problems on their own. For example, in *model-exploration activities*, teachers guide students through particular problem-solving strategies and then provide students opportunities to apply them. In *model-eliciting activities*, teachers help students formalize mathematical concepts by having them explore, test, and revise their own ways of thinking (Lesh, Yoon, & Zawojewski, 2007). According to the Institute of Education Sciences Practice Guide (Pashler et al., 2007), improved learning can take place when these activities involve connecting abstract with concrete representations of concepts.

Using multiple cycles of both kinds of activities is likely the best option to help students learn formalized mathematical concepts and how to solve the kinds of open-ended problems they will encounter outside of school. Recently, the National Mathematics Advisory Panel (NMAP; 2008) recommended a balanced approach because strands of mathematical proficiency, including strategic competence and procedural fluency, "are not independent; they represent different aspects of a complex whole" and "are interwoven and interdependent in the development of proficiency in mathematics" (p. 116). Indeed, research suggests that procedural skills and conceptual understanding develop in an iterative fashion, with gains in one type of knowledge leading to gains in the other (e.g., Rittle-Johnson, Siegler, & Alibali, 2001). Thus, through problem-solving activities students gain practice with procedural skills, which will facilitate future problem solving (National Research Council, 2001).

Recent studies suggest that carefully designed model-exploration and model-eliciting activities can be taught across curricular areas. For example, the National Research Center for Career and Technical Education brought together career/technical education teachers and math teachers to develop instructional activities that taught basic math skills in the context of applied problems. After 1 year, students in the math-supported career/technical education group outperformed students in the comparison group (Stone, Alfeld, Pearson, Lewis, & Jensen, 2006). This improvement was due in large part to how technology education teachers embedded instruction of math skills and concepts in problem contexts. Rather than emphasizing just "tool skills" as was the case in traditional industrial arts classrooms (Frank & Barzilai, 2006; Sanders, 2001), teachers in modern technology education classes used computer and hands-on applications (International Society for Technology in Education, 2007).

While teachers and curriculum specialists often decide what and how mathematics is taught, it is ultimately principals who influence the extent to which these initiatives are carried out (Leithwood & Jantzi, 2008; Pelfrey, 2006; Smith, Wilson, & Corbett, 2009). Making decisions about how best to deliver mathematics instruction becomes problematic for many school administrators because they often have less experience addressing math innumeracy than reading and writing illiteracy (McEwan, 2000). Principals must also consider ways of implementing newer technology applications that promise to enrich the learning experiences of students in mathematics (Shelly, 2002). Finally, whatever plans are developed must also include considerations about appropriate instruction for low-achieving students who often display oppositional behaviors in response to typical math instruction (Hand, 2010). The overall goal of this article is to provide school leaders with classroom-based research that describes one way of addressing these issues.

Background

Over the past decade, our research teams have developed and tested ways to improve the math skills of students using an instructional method called Enhanced Anchored Instruction (EAI; e.g., Bottge, 1999; Bottge, Heinrichs, Chan, & Serlin, 2001; Bottge, Rueda, LaRoque, Serlin, & Kwon, 2007; Bottge, Rueda, & Skivington, 2006; Cho, Bottge, Cohen, & Kim, in press). Similar to the way National Research Center for Career and Technical Education designed its instructional approach, EAI embeds basic skills instruction in authentic-like problems to strengthen students' skills in both computation and problem solving. Originally designed for low-performing students, EAI has been effective with middle school students across a range of abilities (e.g., Stephens, Bottge, & Rueda, 2009).

EAI is modeled after *anchored instruction* (Cognition and Technology Group at Vanderbilt, 1990, 1997) and shares some of the same characteristics as problem-based learning used in medical education and other professions (Barrows, 1996; Gijbels, Dochy, Van den Bossche, & Segers, 2005): (a) instructors use probing questions to guide student understanding of authentic-like problems; (b) students work together in small groups to discuss, test, and find solutions to the problems; and (c) instructors provide in-depth instruction on skills and concepts as students need them. In a typical EAI sequence, students work on a multimedia-based problem in math or special education settings and then apply the skills they have learned to solve a hands-on problem in the technology education classroom. Thus, both EAI and problem-based learning afford students multiple opportunities to practice their skills in several problem contexts, an important requisite for skills transfer (Brown, Collins, & Duguid, 1989; Greeno & the Middle School Mathematics Through Applications Project Group, 1998).

One of the main advantages of EAI is its ability to directly immerse students in active problem contexts versus requiring students to decode text-based (word) problems. This is important because many students who have difficulty in math also have difficulty in reading (Fuchs & Fuchs, 2002; Lesh & Kelly, 2000). Early studies with EAI showed the need for more support in helping students understand the problems themselves. To address this need, hands-on problems and media-based scaffolds were added to the instructional materials, which provided students with multiple representations of the problems, different ways to demonstrate their understanding, and alternative avenues of engagement. These accommodations align with the key principles in Universal Design for Learning (Center for Applied Special Technology, 2009) and are especially important for helping students understand rational number concepts (e.g., fraction equivalence) and computational strategies with fractions. These modifications in the primary learning goals of EAI addressed the need to balance the efficiency-oriented dimension of mathematics learning (i.e., procedural fluency) while maintaining the innovation that emerges from problem exploration (Bransford, Derry, Berliner, Hammerness, & Beckett, 2005).

The present study was similar to our previous research in that it tested the efficacy of EAI for improving the mathematical skills of middle school students. However, it differed from our prior work in two important ways. First, participating technology education teachers taught EAI in their classrooms without support from math teachers. Second, we tested two versions of EAI: One version (*Explicit*) provided formal direct instruction on fractions computation while the other EAI version (*Embedded*) taught fractions computation as needed in the context of the EAI problems.

Specifically, this study was designed to answer the following questions:

1. What are the overall effects of EAI on the math skills of middle school students taught by technology education teachers in technology education classrooms?
2. Do the findings in Point 1 differ depending on whether procedural skills (e.g., adding and subtracting fractions) are taught explicitly in stand-alone units or embedded in problem solving contexts?

Method

The study employed a randomized pretest-posttest comparison group design to answer the research questions. Six intact technology education classrooms at each of three participating middle schools were randomly assigned to one of two EAI conditions or a Business as Usual (BAU) condition. The first EAI condition (*Explicit*) included a fractions module, a multimedia-based problem-solving module, and a hands-on problem. The second EAI condition (*Embedded*) consisted of two multimedia-based problem-solving modules and a hands-on problem. The only difference between the two EAI conditions was the substitution of the explicit unit for one of the problem-solving units. We have named the first condition *Explicit* instruction because fractions computation was taught directly in discrete units just prior to the problem-solving and hands-on units. We refer to the second condition as *Embedded* instruction because students were taught fractions computation as they solved the anchored problems rather than in one stand-alone unit. Criterion-referenced and standardized tests were administered to students prior to and following instruction.

Participants

A total of 303 students in 18 intact technology education classes at three middle schools in the Midwest participated in the study. Table 1 shows demographic information of students by instructional condition and school. Six classrooms were assigned to the *Explicit* condition, five classrooms were assigned to the *Embedded* condition, and seven were assigned to BAU. Sheraton and Lincoln Middle Schools are located in a medium-sized city and McDermott is located in a nearby suburban school district. Demographic data showed diverse student populations across the three schools. At Sheraton 53% were students of color, 57% were eligible for free or reduced lunch, and 23% were receiving special education services. At Lincoln 39% were students of color, 25% were eligible for free or reduced lunch, and 18% were receiving special education services. At McDermott, 9% were students of color, 6% were eligible for free or reduced lunch, and 14% were receiving special education services.

As indicated, chi-square tests of equal proportions showed that the groups were comparable in gender, grade, ethnicity, and ESL. For disability, the proportion of students with a disability versus those without a disability is compared. The numbers of students within disability category were simply too small to compare. There was a difference in schools because only one class at McDermott was randomly assigned to Embedded and three classes were randomized to BAU. Randomization resulted in uneven numbers of schools in instructional conditions.

Technology education was a course requirement for students at all three middle schools. The technology education classes at Lincoln and McDermott were taught with the support of special education teachers. At Sheraton, a computer education teacher with previous experience as a special education teacher assisted the technology education teacher. The teachers had between 5 and 15 years of teaching experience. There was no evidence that differences in staffing or teaching experience affected the results (see Results section).

Instructional Materials and Methods

Explicit condition. The *Explicit* condition consisted of three units of instruction. The objective of the first unit was to provide students with key learning experiences that would develop their knowledge of fraction equivalence and computational fluency with fractions. Instruction emphasized helping students understand the meaning of

Table 1. Description of Students in Explicit, Embedded, and Business-as-Usual (BAU) Classes

	Explicit Condition		Embedded Condition		BAU Condition				
Descriptors	*n*	%	*n*	%	*N*	%	Total	χ^2	*p*
Gender								0.698	.706
Boys	54	34	40	25	64	41	158		
Girls	54	37	39	27	52	36	145		
Middle schools								12.55	.014
Lincoln	39 (2)	33	34 (2)	29	44 (2)	38	117 (6)		
Sheraton	33 (2)	39	29 (2)	34	23 (2)	27	85 (6)		
McDermott	36 (2)	36	16 (1)	16	49 (3)	48	101 (6)		
Grade								0.415	.813
6	39	33	34	29	44	38	117		
7	69	37	45	24	72	39	186		
Ethnicity								11.72	.069
European American	80	36	53	23	93	41	226		
African American	9	32	11	39	8	29	28		
Hispanic	3	21	4	29	7	50	14		
Asian American	16	46	13	37	6	17	35		
Disability								0.466	.792
LD	5	35	2	15	7	50	14		
LD/ADHD					1	100	1		
LD/SL	1	100					1		
Autism			2	100			2		
CD	2	67			1	33	3		
EBD	1	25	2	50	1	25	4		
SL	1	16	2	33	3	50	6		
CP			1	100			1		
OHI	4	36	1	9	6	55	11		
ESL	5	62	1	13	2	25	8	2.62	.270

Note. LD = learning disability; ADHD = attention deficit hyperactivity; SL = speech/language; CD = cognitive disability; EBD = emotional/behavioral disorder; CP = cerebral palsy; OHI = other health impaired. Numbers in parentheses indicate number of classes.

fraction notation and equivalent fractions so that fraction addition and subtraction would make more intuitive sense (Baroody & Coslick, 1998; Hiebert & Carpenter, 1992; Smith, 2002; Star, 2005). This was important because it could effectively reduce the number of procedures students would have to remember as they added and subtracted fractions.

The central activity involved students making fractions strips to represent equivalent fractions, which they then used in computing with fractions. For example, students were given four long strips of paper and asked to imagine the first strip was a long candy bar shared by two people. The students decided to share the candy bar by folding the paper in half. The teacher then directed them to label the fold to indicate the relative size of the candy bar to that point (1/2). The students repeated the process with three more strips—representing candy bars that needed to be shared among 4, 8, and 16 people—using repeated folding. Each fold was labeled with its appropriate fraction. Once all four fractions strips were labeled, students were asked to offer any observations.

On subsequent days, students used their fraction strips to solve problems such as “If you have 3/4 of a candy bar and your partner has 1/2 of a candy bar, who has more? How much more? How much do you have together?” Students were also asked to show how they could use their fraction strips to solve addition and subtraction problems such as 3/8 + 1/8 and 1/4 + 5/16. Teachers were encouraged to focus discussion on students’ understanding of fraction equivalency rather than on procedural sequences or memorized rules to find common denominators.

In addition to these whole-class and small-group activities, students worked on instructional units in a software package called *Fractions at Work*, which was especially developed for use with the EAI problems. The goal of *Fractions at Work* was to improve students’ conceptual and procedural knowledge of fractions by illustrating the parts of a fraction, equivalent fractions (e.g., shown on a ruler), and ways of using knowledge of equivalent fractions to add and subtract fractions with like and unlike denominators (see Figure 1). The *Fractions at Work* menu shows a skateboard ramp park and portals to seven self-contained but related instructional lessons. The entire unit—including both fraction strips and *Fractions and Work* activities—was completed within 3 to 7 days.

The purpose of the second and third units of instruction was to improve students’ abilities to solve extended and contextualized problems using fractions. The first of these units was anchored by a multimedia-based instructional package called *Fraction of the Cost*, which presents a story of three friends who want to build a skateboard ramp. They find schematic plans for a ramp on a website and then discuss what building materials they already have available and whether they have enough money to buy the remaining materials needed to build the ramp. Students need to determine whether the ramp can be built and, if so, what combinations of lengths of the two-by-four (2 in. × 4 in.) lumber they should cut in order to waste as little wood as possible. The problem requires students to use a number of skills, including interpreting schematic plans, reading a tape measure, converting feet to inches, adding and subtracting mixed numbers, and calculating percentages in the contexts of sales tax and bank statements. A screen shot of the main menu is shown in Figure 2.

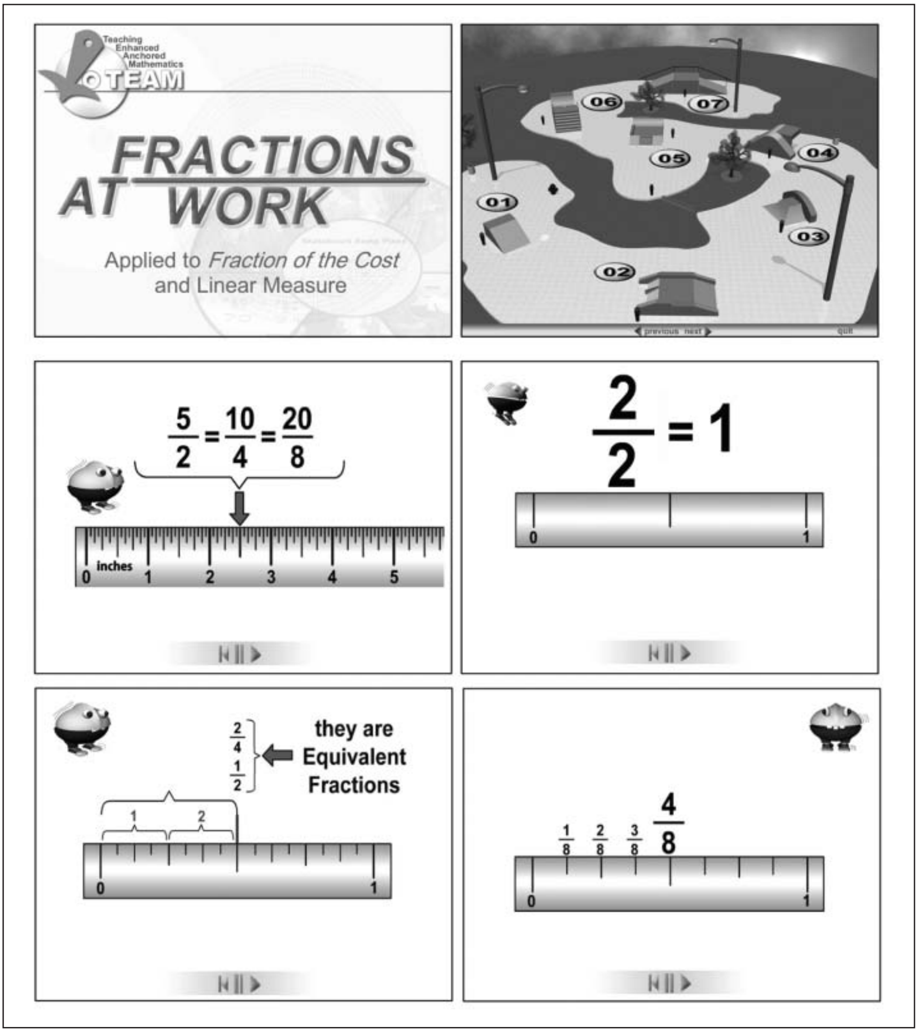

Figure 1. Screen shots from *Fractions at Work*

The *Fraction of the Cost* solution path is not a straightforward one and requires students to continually test their hypotheses until they find a way to buy and use the needed materials while staying under budget. Students can refer to the video anchor throughout their work to find the information they need (e.g., length of available boards, cost of new boards). Interactive scaffolds help students decide the most appropriate ways to solve the problem. For example, students were able to rotate a color-coded skateboard ramp to see all sides and identify parts of the ramp that were the same length. They could also construct the ramp in multimedia space by dragging

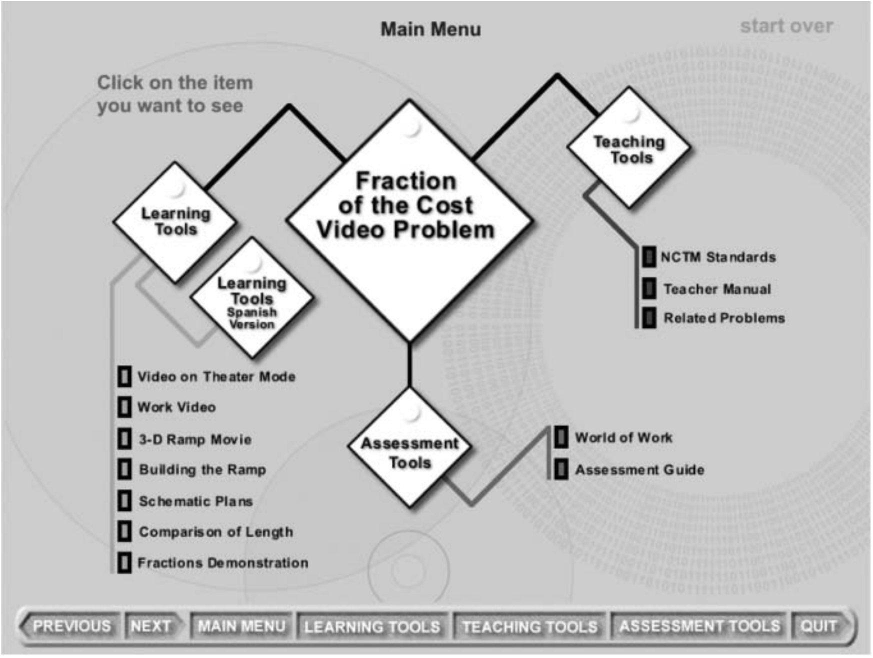

Figure 2. Main menu from *Fraction of the Cost*

individual boards onto a template, thus helping them keep track of which boards they had already accounted for and any remaining boards they still needed to cut. Students could also move a virtual ruler to measure boards before they labeled and "cut" them. At McDermott, the teacher had his students actually build the skateboard ramp featured in the plans. The *Fraction of the Cost* unit took students at each school approximately 10 days to complete.

The final unit of instruction, *Hovercraft*, presents a hands-on, applied problem that requires students to design and build a "rollover" cage for a hovercraft out of PVC pipe. The hovercraft consists of a leaf blower inserted into a hole in a plywood base. A plastic sheet is attached to underside of the base. Small holes are cut in the plastic through which air from the leaf blower passes to elevate the hovercraft slightly off the floor. Students developed plans on grid paper, built a scale model out of plastic straws, and calculated the total cost of materials they needed to purchase. Once the plans and budget were finalized, they used their plans to build full-size hovercraft frames. The skills required for solving the problem include reading a tape measure, converting feet to inches, making a scale drawing, calculating the total cost of materials, and using a two-dimensional representation (the plan on paper) to build a three-dimensional structure (the hovercraft). The 7- to 10-day unit culminated in a day of hovercraft racing that, depending on the school, occurred in a classroom, a school hallway, or the school's gymnasium.

Embedded condition. We refer to this condition as embedded because, while the problem did require work with fractions, students did not receive discrete periods of explicit instruction in this domain. Rather, teachers helped students work with fractions on an as-needed basis while they were solving the video-based problems. The *Embedded* condition was identical to the *Explicit* condition with the exception of the initial unit of instruction. In place of the *Fractions* unit, students solved an additional anchored problem called *Bart's Pet Project*. The content of this problem was similar to *Fraction of the Cost*, but rather than figuring out the most economical way to build a skateboard ramp, students determined the most economical way to build a pet cage. As in *Fraction of the Cost*, students studied a schematic plan, determined the use of available and purchased materials, and calculated a total cost. *Bart's Pet Project* tapped a subset of the skills required by *Fraction of the Cost*, such as converting feet to inches, reading schematic plans, and adding and subtracting mixed numbers.

Business as usual (BAU) condition. In the BAU condition, teachers proceeded with their usual instruction. These units varied widely from school to school (e.g., building and racing dragster cars at Sheraton, reading and summarizing articles on uses of technology at Lincoln, building suspension bridges at McDermott). One important exception must be noted, however. At Lincoln and McDermott, the teachers very much wanted *all* students to have the opportunity to build and race hovercrafts, not only those in the EAI conditions. We therefore came to an agreement that teachers would allow students to experience the full *Hovercraft* unit (at Lincoln) or an abbreviated version (at McDermott) that focused on building rather than on budgeting or calculating the cost of materials. Classroom observers in the BAU classrooms confirmed that, aside from using a tape measure in the *Hovercraft* unit, teachers did not teach the EAI curriculum.

Instructional Support and Fidelity

Teacher training. Teachers learned to implement EAI in several ways. First, they participated in a 2-day workshop during the summer, which was taught by a middle school math teacher who had used EAI in his classes for several years. Teachers were provided notebooks that contained daily lesson plans that included learning objectives and instructional materials. During the workshop, teachers solved problems with fraction strips, watched the problem-solving videos, and solved the practice problems. They also designed, constructed, and raced hovercrafts.

Second, the teachers at Sheraton and McDermott "practiced" implementation of the units during the first quarter of the school year with their students who were not involved in the study. Teachers at these schools taught both the explicit and informal instructional units before formal data collection began. In reflecting on their experiences at the conclusion of the study, these teachers stressed that this practice period improved their familiarity and confidence with the curriculum and increased the quality of the teaching that took place during the study. The teacher at Lincoln Middle School did not need a practice period because he had taught variations of the *Fraction of the Cost* and *Hovercraft* units the previous year.

Fidelity of implementation. Classroom observers used laptop computers to record observation notes directly into an electronic relational database, which was designed especially for the study using FileMaker Pro 7. The observation template included space for observers to record routine information (e.g., date, school, condition, unit of instruction) and verify treatment fidelity (e.g., "completed warm-up activity in lesson plan," "provided students time to problem solve independently or with peers"). Observers became familiar with the template by using it during the first quarter of the school year when teachers at two of the schools were "practicing" the instructional units. One primary observer was at each school and an additional observer visited all three schools. Interrater reliability was calculated for rating scores of 20% of the observations by dividing the number of agreements between the observations of the primary observers by the total number of common observations. Reliability ranged from 94% to 100%.

Data Collection

Two researcher-developed criterion-referenced tests and two standardized norm-referenced achievement measures were used to assess student performance prior to and following instruction. Classroom observers were on hand during all test administrations. Teachers read directions to students from scripts that we provided. Prior to the study, graduate assistants were trained to use answer protocols to score the tests reliably. Interrater reliability was calculated on 20% of pretests and posttests and was computed by dividing the number of agreements by the total number of agreements and disagreements and multiplying by 100 (Sulzer-Azaroff & Mayer, 1977).

Problem-solving test. A 48-point Problem Solving Test was developed by the authors to assess the skills and concepts students learned with EAI. The items were aligned to National Council of Teachers of Mathematics (NCTM; 2000) standards recommended for students in Grades 6 to 8 (i.e., Numbers and Operations, Measurement, Problem Solving, Communication, and Representation). Sets of items were grouped into concept and skill areas and then weighted according to difficulty and contribution to the solution of the overall problem. One group of items measured students' ability to understand a bank statement and calculate 10% and 20% of the balance (see Figure 3). Other items required students to interpret building plans where dimensions were in fractional measurements, figure out how to use the boards to waste as little wood as possible, determine the lengths of unused boards, and calculate the total material costs including sales tax. Within each item set, students could earn partial or full credit (1-6 points) depending on the completeness of their answers.

The Problem Solving Test was similar to versions used in previous studies (i.e., constructed response items, full or partial credit, items weighted according to complexity), but it also differed in important ways. First, it was almost 25% longer than

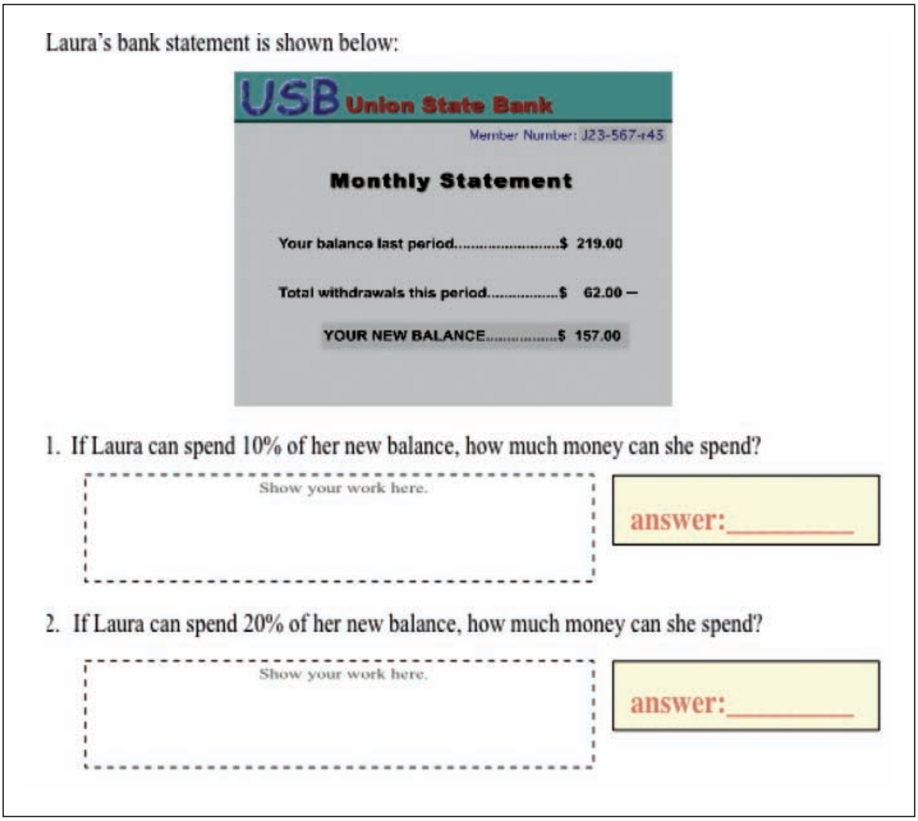

Figure 3. Page from Problem Solving Test

previous versions. Second, although the concepts tested remained the same, the question formats and problem contexts in the new version differed from those students had worked on during instruction. For example, students had to interpret building plans they had never seen before and transfer their applications to new contexts.

Internal consistency estimate (α) was .90, which is consistent with previous problem-solving tests used in two previous studies, .80 (Bottge, Rueda, Serlin, Hung, & Kwon, 2007) and .90 (Bottge, Rueda, Grant, Stephens, & LaRoque, in press). Interrater reliability was 97% based on a random sample of 20% of the protocols scored.

Fraction Computation Test. The Fraction Computation Test consisted of 14 addition and 6 subtraction items and measured students' ability to compute with fractions. Teachers asked students to reduce their answers to simplest form and to show their work. The test consisted of items that involved fractions with like denominators (e.g., 1/4 + 3/4), fractions with unlike denominators where the larger denominator could serve as the common denominator (e.g., 7/8 − 1/4), and unlike denominators where neither denominator could serve as the common denominator (e.g., 8 2/9 + 2 1/2). The items also varied by whether or not the fractions could be found on the markings of a ruler (e.g., 3/4 + 7/8 would fall into this category; 1/5 + 1/3 would not). The test included both simple fractions and mixed numbers. Students could earn 2 or 3 points per item, depending on whether simplification was necessary, for a total of 50 points on the entire assessment. One point was awarded for correctly converting to equivalent fractions with common denominators even if the final answer to the problem was incorrect. Internal consistency of test items (Cronbach's coefficient alpha) was .97. Interrater reliability was 98% based on a random sample of 20% of the protocols scored.

Standardized tests. In addition to the criterion-referenced tests, students took two math subtests of the *Iowa Test of Basic Skills* (ITBS; Form A; University of Iowa, 2001). According to the publisher, the ITBS reflects the spirit of the NCTM *Principles and Standards for School Mathematics* (NCTM, 2000). The *Computation* subtest required operations with whole numbers, fractions, and decimals. The *Problem Solving and Data Interpretation* subtest included word problems that required one or more steps to solve. Some items contained tables and graphs of data to interpret. Both subtests were administered according to the directions in the test administration booklet. According to the publisher of the ITBS, K-R20 (Kuder-Richardson Formula 20) reliability estimates at Level 12 are .814 for the *Computation* subtest and .842 for the *Problem Solving and Data Interpretation* subtest. No errors were found in test scoring and data entry.

Results

Math performance

Table 2 shows the means and standard deviations of the four achievement measures in the three instructional conditions. Students were included in the analyses if they completed both criterion-referenced pretests and posttests. This criterion was met by 240 of the 303 students. Information about students with missing scores indicated that school absences were at random with each student equally as likely to miss an exam day. Using HLM6 (Raudenbush, Bryk, Cheong, & Congdon, 2000) we conducted separate three-level hierarchical linear models to assess possible differences in intercept (i.e., pretest value) and slope (i.e., time of test) between the three treatment groups for each dependent variable (Raudenbush & Bryk, 2002). The structure of the model indicates *i* as student in class *j, t* as the *t*th score for student *i*(pretest, posttest), and time as either 0 for pretest score or 1 for posttest score.

$$
\begin{aligned}
\text{Level 1:}\quad & \text{Score}_{jit} = \pi_{0ij} + \pi_{1ij}(\text{Time}_{jit}) + \varepsilon_{jit} \\
\text{Level 2:}\quad & \pi_{0ij} = \beta_{00j} + r_{0j} \\
& \pi_{1ij} = \beta_{10j} \\
\text{Level 3:}\quad & \beta_{00j} = \gamma_{000} + \gamma_{001}(\text{Explicit}_j) + \gamma_{002}(\text{Embedded}_j) + \mu_{00} \\
& \beta_{10j} = \gamma_{100} + \gamma_{101}(\text{Explicit}_j) + \gamma_{102}(\text{Embedded}_j)
\end{aligned}
$$

Table 2. Pretest and Posttest Means and Standard Deviations by Instructional Condition

		Pretest		Posttest	
Measure	*n*	*M*	*SD*	*M*	*SD*
Problem Solving Test					
Explicit condition	83	13.67	8.95	24.39	14.77
Embedded condition	68	16.60	10.61	28.13	14.34
BAU condition	89	14.54	10.31	21.23	13.05
Fraction Computation Test					
Explicit condition	83	28.01	18.05	32.41	16.55
Embedded condition	68	27.93	18.22	33.63	17.13
BAU condition	89	25.89	17.17	27.32	18.77
ITBS Problem Solving					
Explicit condition	79	240.29	37.78	249.90	34.01
Embedded condition	68	249.69	32.79	252.94	39.08
BAU condition	87	242.05	41.32	244.36	40.99
ITBS Computation					
Explicit condition	79	212.06	27.83	219.30	28.64
Embedded condition	66	220.24	28.55	227.09	26.38
BAU condition	87	212.70	27.99	219.17	30.56

Note. ITBS = Iowa Test of Basic Skills; BAU = business as usual.

Explicit_j is 1 if class j received *Explicit* instruction, 0 otherwise. Embedded_j is 1 if class j received *Embedded* instruction and 0 if class j received *Explicit* instruction or BAU since type of instruction is a class-level variable (Level 3). Therefore, γ_{000} represents the mean initial status (pretest score) for the BAU group, γ_{001} represents the mean incremental initial status for the Explicit group, and γ_{002} represents the mean incremental initial status for the Embedded group. Improvement scores from pretest to posttest are indicated in the next line of the model. The mean growth rate is γ_{100} for the BAU group, γ_{101} represents the average additional growth rate for *Explicit* instruction, and γ_{102} represents the average additional growth rate for *Embedded* instruction. The model contains only one random effect on intercept at the classroom level as the analysis makes the typical assumption of homogeneity of variance, specifically that the variability within classes is constant over time. Effect size (ES) is reported on change scores of the BAU group (γ_{100}) and for the additional increase due to EAI in the Explicit(γ_{101}) and Embedded(γ_{102}) groups. It was computed for both Explicit and Embedded instructional groups by dividing the growth rates by the standard deviation of the difference scores

$$\left(ES = \frac{\gamma}{\sqrt{S_{\mathrm{PRE}}^2 + S_{\mathrm{POST}}^2 - 2\rho_{\mathrm{PRE,POST}} S_{\mathrm{PRE}} S_{\mathrm{POST}}}} \right).$$

Table 3. HLM Model of Treatment Effects on the Problem Solving Test

Fixed Effects	Coefficient	*SE*	*t*	*df*	*p*
BAU pretest γ_{000}	17.118	3.046	5.621	13	<.001
Explicit instruction advantage at pretest γ_{001}	−0.693	4.480	−0.155	13	.880
Embedded instruction advantage at pretest γ_{002}	0.485	4.482	0.108	13	.916
BAU improvement (pretest to posttest) γ_{100}	4.375	0.952	4.597	408	<.001
Additional improvement for explicit instruction γ_{101}	3.222	1.371	2.351	408	.019
Additional improvement for embedded instruction γ_{102}	5.243	1.365	3.839	408	<.001

Random Effects	Standard Deviation	Variance Component	*df*	χ^2	*p*
Time of test e_{ijt}	5.710	32.602			
Student level r_{0j}	9.243	85.424	191	1190.8	<.001
Class level u_{00}	6.713	45.066	13	105.4	<.001

Note. BAU = business as usual.

Results of the *Problem Solving Test* are shown in Table 3 and displayed in Figure 4. Pretest scores did not differ between the Explicit and BAU groups or between the Embedded and the BAU groups. The hierarchical model showed that BAU scores improved from pretest to posttest (ES = 0.44). Additional improvements over the BAU group were found for the Explicit group (ES = 0.32) and the Embedded group (ES = 0.53). The difference in the amount of improvement made by students in the Explicit and Embedded groups was not statistically different, $t(408) = 1.481$, $p = .140$, ES = 0.20.

A more fine-grained analysis of performances on the *Problem Solving Test* was conducted on items that required students to (a) calculate percentages, (b) read a tape measure, (c) interpret a scale drawing, (d) add and subtract fractions, (e) convert feet to inches, and (f) calculate monetary quantities. At the item subset levels, results showed that students in the EAI groups scored higher than students in the BAU group on several skills. Students in the Embedded condition showed greater improvement than students in the BAU condition on items requiring reading of a tape measure ($t = 3.03$, $p = .003$, ES = 0.52). On items requiring addition and subtraction of fractions, students in the Explicit classes showed greater improvement than students in the BAU condition ($t = 3.05$, $p = .003$, ES = .65). Students in the Explicit condition also showed greater improvement than students in the Embedded ($t = 4.04$, $p < .001$, ES = 1.19) and BAU conditions ($t = 2.44$, $p = .017$, ES = .53) on items requiring the addition or multiplication of monetary quantities.

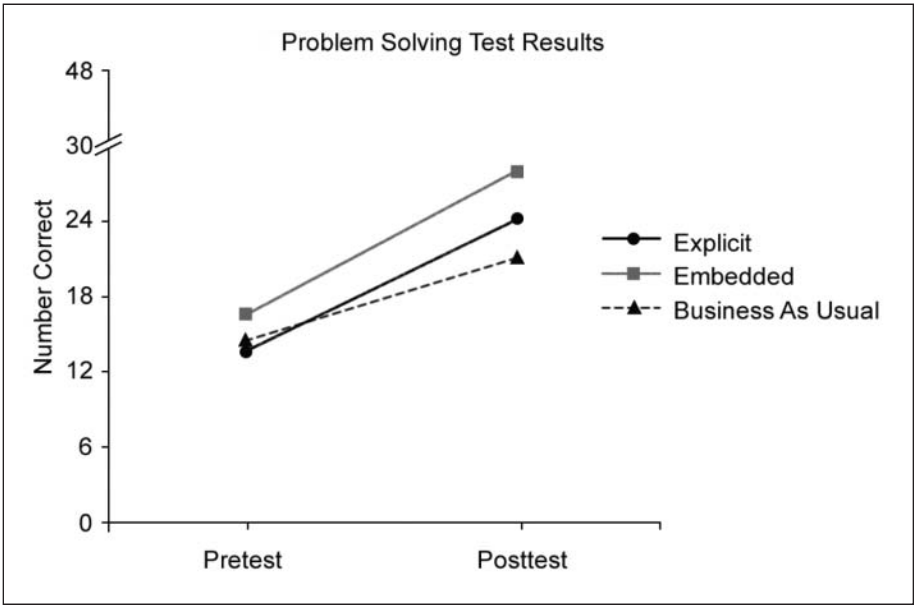

Figure 4. Results of the Problem Solving Test

On the *Fraction Computation Test*, Table 4 shows that there were no significant pretest differences between groups or main effect for the BAU group at time of test (pre, post) (ES = 0.26). The Embedded instruction group showed a statistically significant improvement over the BAU group (ES = 0.42), but there was no additional improvement by the Explicit group over the BAU group (ES = 0.19; see Figure 5). There was also no statistically significant difference between Embedded and Explicit instruction, $t(408) = 1.143$, $p = .140$, ES = 0.23.

To determine on which skills instruction had most effect, sets of items were grouped according to (a) operation (i.e., addition and subtraction), (b) whether or not they involved fractions that are found on a ruler, and (c) type of denominator (i.e., like denominators, unlike denominators where the larger denominator could serve as the common denominator, and unlike denominators where neither denominator could serve as the common denominator). Students in the Embedded condition showed greater improvement than students in the BAU condition on the following items: computing with like denominators ($t = 2.48$, $p = .01$, $d = .37$), computing with fractions found on a ruler ($t = 2.93$, $p = .004$, $d = .49$), and subtraction items ($t = 2.86$, $p = .005$, $d = .49$). No other differences were found.

On the two ITBS subtests, there were no pretest differences between the three groups. On the *ITBS Problem Solving and Data Interpretation Test* (Table 5), there was no statistically significant posttest gain for the BAU group and no additional benefit from being in the EAI groups. Estimates of pretest and posttest scores were 240.29

Table 4. HLM Model of Treatment Effects on the Fractions Computation Test

Fixed Effects	Coefficient	Standard Error	*t*	*df*	*p*
BAU pretest γ_{000}	26.243	3.623	7.244	13	<.001
Explicit instruction advantage at pretest γ_{001}	1.904	5.309	0.359	13	.725
Embedded instruction advantage at pretest γ_{002}	0.486	5.313	0.091	13	.929
BAU improvement (pretest to posttest) γ_{100}	2.194	1.166	1.881	408	.060
Additional improvement for explicit instruction γ_{101}	1.597	1.680	0.950	408	.343
Additional improvement for embedded instruction γ_{102}	3.511	1.674	2.098	408	.036
Random Effects	**Standard Deviation**	**Variance Component**	***df***	**χ^2**	***p***
Time of test e_{ijt}	6.998	48.977			
Student level r_{0j}	14.154	200.333	191	1754.3	<.001
Class level u_{00}	7.519	56.538	13	69.25	<.001

Note. BAU = business as usual.

and 249.90 for the Explicit group and 249.69 and 252.94 for Embedded group, respectively. On the *ITBS Computation Test* (Table 6), results revealed a main effect for time of test (pre, post), $t(372) = 2.005$, $p < .045$, ES = 0.23. No other significant main effects or interactions were found. Estimated pretest and posttest scores increased from 220.24 to 227.09 for students in the Embedded group and from 212.06 to 219.30 for students in the Explicit group, respectively.

Discussion

The purpose of this study was to test two forms of EAI taught by technology education teachers on students' computation and problem-solving skills. One version employed an explicit fractions unit prior to the problem-solving units. The other version was identical to the first except that students solved an additional EAI problem in place of the explicit fractions unit and fractions instruction was embedded in the problems. We compared the effects of both EAI interventions to that of students who were taught with their usual curriculum.

Results from the criterion-referenced tests showed differences in both problem solving and computation. Consistent with findings of previous studies using EAI (e.g., Bottge et al., 2007 **Is this Bottge, Rueda, LaRoque, Serlin, & Kwon, 2007, or Bottge, Rueda, Serlin, Hung, & Kwon, 2007? Please confirm which reference is**

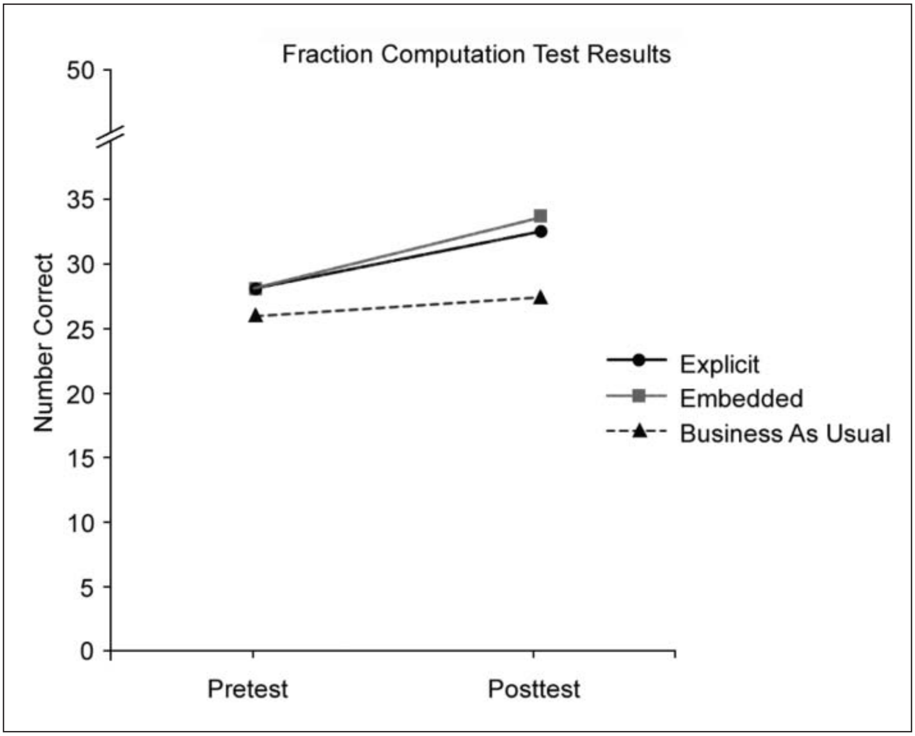

Figure 5. Results of the Fraction Computation Test

being cited), results showed students who were taught with either version of EAI outperformed students in the BAU condition on the *Problem-Solving Test*. Particularly important were the gains of students in the EAI classes on key subsets of skills including performance in reading a tape measure and computing with fractions. On the *Fractions Computation Test*, students in both EAI groups scored higher on the posttest than students in the BAU classes. However, only the students in the Embedded group showed more improvement from pretest to posttest than students in the BAU condition. The scores of students in the explicit instruction group were higher on the posttest than on the pretest, but the size of their improvement only approached significance compared to that of students in the typical instruction group.

This latter finding is particularly important because it reinforces the NRC and NMAP recommendations that procedural skills can be learned when they are embedded in interesting problems. In this study, students were motivated to solve the problems in *Fraction of the Cost* and the *Hovercraft* challenges. When they were unsure of how to compute their answers, teachers provided them with just-in-time instruction. The higher posttest scores suggest that students remember both problem solutions and computational procedures when learning is tied closely to engaging learning activities. Scholars

Table 5. HLM Model of Treatment Effects on the Iowa Test of Basic Skills Problem Solving and Data Interpretation Subtest

Fixed Effects	Coefficient	Standard Error	t	df	p
BAU pretest γ_{000}	242.445	6.270	38.667	13	<.001
Explicit instruction advantage at pretest γ_{001}	–0.976	9.231	–0.106	13	.918
Embedded instruction advantage at pretest γ_{002}	9.069	9.170	0.989	13	.341
BAU improvement (pre to posttest) γ_{100}	0.000	3.344	0.000	372	>.999
Additional improvement for explicit instruction γ_{101}	6.237	4.906	1.271	372	.205
Additional improvement for embedded Instruction γ_{102}	1.097	4.842	0.227	372	.821
Random Effects	**Standard Deviation**	**Variance Component**	df	χ^2	p
Time of test e_{ijt}	19.498	380.182			
Student level r_{0j}	30.909	955.377	173	1,030.0	<.001
Class level u_{00}	10.651	113.447	13	35.39	.001

Note. BAU = business as usual.

such as Dewey (1938), Wertheimer (1959), and Bruner (1960) have all urged educators to find problems that generate this kind of purpose in students.

This finding, however, departs from a companion study that involved students with learning disabilities in math. In that study, students in the explicit instruction condition improved significantly more on the computation test than students in the embedded and BAU instructional conditions (Bottge et al., in press). Unlike the students in the present study, these students had very little of knowledge of fractions to begin with and posted an average pretest score of only 3 out of 50. The explicit instruction unit had a major effect, raising student scores to an average of 30 points on the posttest. Thus, it is quite possible that explicit instruction in combination with EAI is a power UDL factor and beneficial when students are at the beginning of the learning trajectory but not as necessary when students already have some competency with the skill set.

The fact that students showed some improvement on the *Fractions Computation Test* is not a trivial finding. Fractional concepts are among the most complex that mathematics students encounter (Charalambous & Pitta-Pantazi, 2007; Smith, 2002) and have posed major obstacles to mathematical development (Behr, Harel, Post, & Lesh, 1992; Calhoon, Emerson, Flores, & Houchins, 2007; Kloosterman, 2010; Post, Wachsmuth, Lesh, & Behr, 1985). Compounding the issue is the fact that students are

Table 6. HLM Model of Treatment Effects on the Iowa Test of Basic Skills Computation Subtest

Fixed Effects	Coefficient	Standard Error	t	df	p
BAU pretest γ_{000}	212.787	5.022	42.372	13	<.001
Explicit instruction advantage at pretest γ_{001}	−1.180	7.398	−0.159	13	.876
Embedded instruction advantage at pretest γ_{002}	7.229	7.355	0.983	13	.344
BAU improvement (pre to posttest) γ_{100}	5.044	2.516	2.005	372	.045
Additional improvement for explicit instruction γ_{101}	3.786	3.691	1.026	372	.306
Additional improvement for embedded instruction γ_{102}	1.714	3.643	0.470	372	.638
Random Effects	**Standard Deviation**	**Variance Component**	df	χ^2	p
Time of test e_{ijt}	14.670	215.206			
Student level r_{0j}	23.177	537.182	173	1,031.2	<.001
Class level u_{00}	9.053	81.956	13	39.94	<.001

Note. BAU = business as usual.

likely to have less out-of-school experience on which to build their understanding of rational numbers than is the case with whole numbers (NRC, 2001). In this study, technology education classrooms provided students with especially rich contexts for working with rational numbers in solving practical problems.

In addition to the positive findings on the criterion-referenced tests, standardized test results indicated elevated posttest scores on both subtests. This finding is especially impressive given the relatively short length of the instructional interventions. Although the improvement in the means of the standard scores may not appear large, the effect sizes obtained in this study would place them in the medium range (Cohen, 1977).

Despite these positive findings, we temper our conclusions with the following limitations. First, teachers in some of the BAU classes allowed students to build the skateboard ramp, which students in the EAI conditions also constructed. Teachers thought that building the ramp would align with the existing goals of their course and would provide a more authentic experience for the students. However, the students in the BAU classes were not taught the math skills the students in the EAI conditions received. Although this is stated as a limitation to the implementation fidelity in the study, it actually strengthens our conclusions because some students in BAU classes received a part of the curriculum that was part of the intervention conditions.

Second, relatively few technology education classes were involved in the study, which may have limited the ability to detect changes when they were in fact present (i.e., power). We are currently recruiting 34 middle schools to conduct a similar study randomizing intervention at the school level. The findings from that study should help us to more confidently assess the effects of EAI.

Educational Implications

The 2007 National Assessment of Educational Progress (Lee et al., 2007) showed that 26% of students without disabilities scored below the *Basic* level. To achieve *Basic*, students "should complete problems correctly with the help of structural prompts such as diagrams, charts, and graphs" and demonstrate "the appropriate use of strategies and technological tools to understand fundamental algebraic and informal geometric concepts in problem solving" (p. 20). Thus, scoring below *Basic* suggests students have few fundamental skills at the given grade level.

Results of this study showed that students are able to improve their math skills when instruction is organized in ways that are described in the Institute of Education Sciences Practice Guide for organizing instruction to improve learning (Pashler et al., 2007). First, the computer-based instructional tools together with the applied problem resulted in higher problem-solving performances. Graphics, verbal descriptions, and interleaved work samples all combined to improve student performance.

Second, the findings suggest that it was important to combine multimedia-based instructional tools (i.e., *Fractions at Work, Fraction of the Cost, Bart's Pet Project*) with concrete representations of similar concepts (i.e., *Hovercraft*). Although most students found the multimedia tools helpful, some students needed to experience the problems through hands-on instruction. The application problem served the dual purpose of engaging students in the learning task and providing them with ways to integrate and practice their understanding of concepts using life-sized manipulatives.

Third, these findings and recent reviews of math education (Maccini, Mulcahy, & Wilson, 2007; Woodward, 2004) suggest that a new theoretical model for adolescents, especially for those who are low achievers in math, should be developed and tested. The new model should consider the reciprocal benefits of teaching computation and problem solving in complementary ways, following the advice of researchers in cognitive science and mathematics education (NMAP, 2008). It should also help students develop a *productive disposition* (NRC, 2001) by conveying that math is sensible, useful, and worthwhile. To engender this feeling among adolescents will require that teachers with the support of their administrators develop instructional methods and materials matched more closely to what students regard as purposeful. Older students need to see explicit connections between what they are expected to learn and how it will help them in the future. This redesign will most likely include the need for an expanded use of technology and more complex math content, which in turn will require more staff development (Maccini & Gagnon, 2006; Stodden, Galloway, & Stodden, 2003; Stone, Alfeld, & Pearson, 2008). This can be accomplished not only in technology education classrooms but in regular content classrooms and special education settings as well.

Finally, these findings suggest that important advances can be made in developing students' mathematics skills across content areas using carefully constructed instructional tools. Educational leaders will face the challenge of integrating these applications in their schools to improve the academic achievement of students to the level that national, state, and local standards recommend. In particular, leaders will need to identify ways of either merging effective technology-based instructional applications with traditional methods of teaching mathematics or reconceptualize the teaching of mathematics altogether. This will require locating appropriate resources that can provide teachers with the professional development necessary to implement newer curricula such as the kind described in this study.

In our future research, we hope to expand our instructional tools with sophisticated computer-based, formative assessments that measure students' progress on the EAI problems and basic skills in valid and reliable ways (e.g., Bottge, Rueda, Kwon, Grant, & LaRoque, 2009). Our goal is to help all students improve their math skills by involving teachers across curricular areas. In doing so, we hope address some of the concern over how well schools are preparing students for postsecondary opportunities and future employment (e.g., Education Testing Service, 2007).

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The authors declared no conflicts of interest with respect to the authorship and/or publication of this.

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