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ABSTRACT

Multi-line-multi-operation calculators such as the TI-80 provide eighth-grade prealgebra and algebra students with significantly better computational tools for basic order-of-operation problems involving integers and signed rational numbers than do calculators offering only last-entry-or-result displays. Effects are more apparent for weaker students and in more complicated problems involving the distributive property. (Author)

The Day the Calculator Changed: Visual Calculators in Prealgebra and Algebra

John E. Owens

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(17th PME-NA, Columbus, OH, October 21-24, 1995)

THE DAY THE CALCULATOR CHANGED: VISUAL CALCULATORS IN PREALGEBRA AND ALGEBRA

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Multi-line-multi-operation calculators such as the TI-80 provide eighth-grade prealgebra and algebra students with significantly better computational tools for basic order-of-operation problems involving integers and signed rational numbers than do calculators offering only last-entry-or-result displays. Effects are more apparent for weaker students and in more complicated problems involving the distributive property.

The literature on calculator usage to date (with the exception of some recent studies of graphing capabilities) is based on Last-Entry-or-Result display (LER) calculators. Historically, studies have tended to focus on the effect of calculator usage on students' pencil & paper-based computational skills and attitudes toward mathematics rather than on the nature of students' interaction with the calculator (Hembree & Dessart, 1992). Calculators tend to be treated as "computational experts" useful for their ability to do quick and accurate arithmetic.

More recently calculators have begun to be investigated for a more meaningful role in the learning of mathematics. (Hirschhorn & Senk, 1992; Bitter & Hatfield, 1993). However, the question as to whether or not the visual feedback from the calculator might not be consistent with (or even in direct conflict with) students' written or mental representations of an expression seems, in these studies, not an object for investigation but an obstacle overcome by teaching students the calculator's mode of entry. This is quite understandable given the current nature of non-graphing calculators. But the fact that inexpensive dot-addressable displays are now becoming widely available suggests that this need no longer be the case—reasonably priced calculators can be designed that mimic hand and text-based operations.

Limited recognition of the potential of Multi-Line-Multi-Operation display (MLMO) calculators as teaching tools has begun to appear (Vonder Embse, 1992); but these calls are deficient in two ways: They lack a basis in theory and an empirical research base. This study is the first in a series of planned investigations into the use of MLMO calculators as tools for doing and learning mathematics and the nature of student interaction with various calculator displays.

As a first step, students in eighth-grade prealgebra and algebra were tested on selected skills involving order-of-operation problems with integers and rational numbers to determine what, if any, advantage MLMO displays have over LER displays.

Subjects

Participants in the study were four intact classes of eighth grade students at a local middle school. Two of the classes were first-year algebra (the only first-year algebra classes taught at the school); the others were two of the four eighth grade mathematics (primarily prealgebra) classes taken by all eighth-grade students not

enrolled in algebra. All four classes under consideration were taught by the same teacher so as to minimize teacher effects. Data were collected during the final month of the 1994-95 school year.

All eighth-grade students in North Carolina take a state-constructed end-of-grade mathematics test consisting of eight components, seven of which are calculator-active. Texas Instruments' TI-12 Math Explorer is the recommended calculator and was used by all students during the year and for this test ("graphing" calculators have been excluded from use on this test on a state-wide basis). In addition, students in first-year algebra take a state-constructed end-of-course test requiring use of a graphing calculator.

Texas Instruments' TI-81 graphing calculators were used extensively during the year in the algebra class with minimal preparation on the use of TI-12s in preparation for the end-of-grade exam. Prealgebra classes used TI-12s extensively with some introduction to TI-81s.

Method

Students completed three forms of an instrument (see Instruments, below) designed to ascertain their proficiency with certain prealgebra and algebra skills. In each case, classes received approximately three days of review/instruction prior to the administration. The first instance of the instrument was completed manually (without calculator); half of the classes (one prealgebra, one algebra) completed the second instance using LER calculators and the third using MLMO calculators, while the other two classes reversed this sequence (in order to minimize possible sequencing bias). Administration of the instruments was untimed. Only students who completed all three sittings of the instruments (61 students—33 algebra and 27 prealgebra—approximately 75% of the original classes) were included in the analysis.

Instruments

The instrument consisted of 24 problems, four problems each (two using integers, two using rational numbers) in six groups: Simple addition/subtraction; simple multiplication/division; complex addition/subtraction; complex multiplication/division; simple distributive; and complex distributive (see Figure 1). Problems were selected and written to conform to the type and format of problems worked by the students during the year.

Three equivalent forms of the instrument were developed. In each case equivalent problems maintained signs and operations, changing only the numbers to reduce student reliance on memory of previous forms to generate answers. For example, the problem $^{-}2-^{-}3$ on form 1 was changed to $^{-}1-^{-}2$ on form 2 and $^{-}2-^{-}4$ on form 3.

Equipment

Calculators used in the study were Texas Instruments' TI-12 Math Explorer and TI-80 graphing calculator. The TI-12 was chosen as the LER based on student

$\frac{1}{2} - -2\frac{1}{4}$	Simple A/S
$4(-2)$	Simple M/D
$2\frac{1}{3} - -3\frac{1}{2} + 4\frac{2}{3} - -3\frac{1}{4}$	Complex A/S
$-4 - -2 \div -1 + 3 \div -2$	Complex M/D
$3\frac{1}{3}\left(-2\frac{2}{3} - 3\frac{1}{4}\right)$	Simple Dist.
$2(-4 - -3) - 2(1 + -4)$	Complex Dist.

Figure 1. Sample Problems

familiarity with the calculator. The TI-80 is a new calculator, introduced in 1995, that combines the eight-line display capabilities of the TI-81 with the fraction operations of the TI-12 (see Figure 2). This calculator was chosen as the MLMO model based on student familiarity with TI-12 and TI-81 operations.

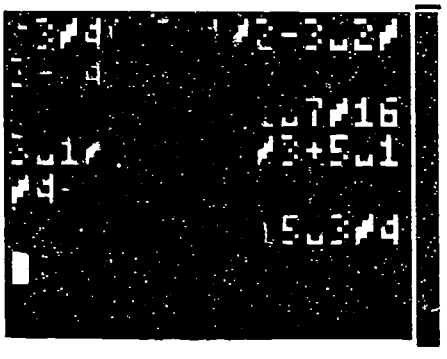

Figure 2. Sample TI-80 Screen

Results

Results were analyzed using SPSS-PC v6.1. Comparing means by question indicated significant differences in all pairwise combinations (Manual vs LER, Manual vs MLMO, LER vs MLMO) using t-tests for paired samples (2-tail significance, $p<.0005$).

An analysis of variance for sex-related differences showed significance ($p<.0005$) only for manual calculations in prealgebra. It is interesting to note that in prealgebra classes girls outscored boys in each of the three instances (although only manual comparisons were significant). However, in the algebra classes boys outscored girls on manual computations, but were outscored by the girls on both LER and MLMO implementations (although no differences were significant).

Average time taken by students for LER and MLMO calculations were virtually identical, while times taken for manual operations were significantly longer

for both algebra and prealgebra classes. Order of implementation (i.e., LER before MLMO or vice-versa) was not significant. (see Table 1).

Table 1
Mean and Standard Deviation

	Algebra		Prealgebra	
	Score	Time	Score	Time
Manual	.43/.13	37.65/12.59	.20/.11	26.74/6.44
LER	.82/.12	19.03/5.99	.62/.15	19.56/7.30
MLMO	.93/.10	20.00/6.36	.84/.12	20.33/5.60

More detailed analyses were carried out by question. Table 2 describes significant differences by question. (See also Figure 3 and Figure 4). Additional analyses by student were performed but are not reported in this paper.

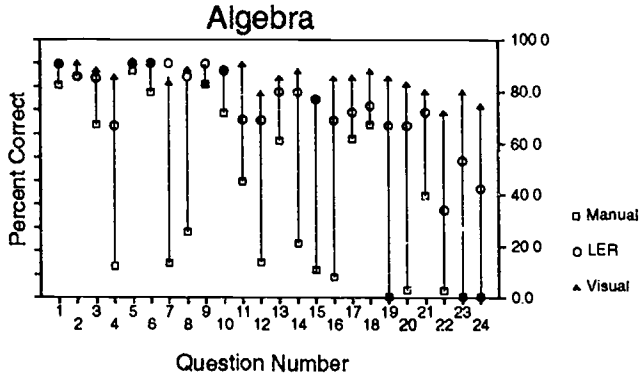

Figure 3. Algebra by Question

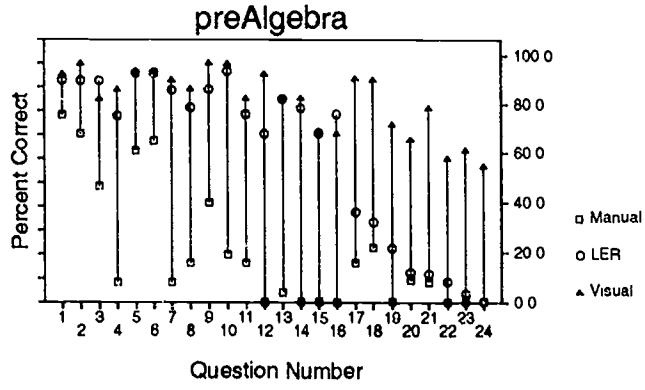

Figure 4. Prealgebra by Question

Table 2
Significant Differences by Question

	Significant Differences by Question (p_.01)																							
	Simple Add/Sub				Complex Add/Sub				Simple Mult/Div				Complex Mult/Div				Simple Dist.				Complex Dist.			
	Integer		Rational		Integer		Rational		Integer		Rational		Integer		Rational		Integer		Rational		Integer		Rational	
Algebra	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
M vs L				#			#	#				#		#	#	#			#	#	#	#	#	#
M vs V			#	#			#	#			#	#	#	#	#	#	#	#	#	#	#	#	#	#
L vs V											#											#	#	#
preAlgebra	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
M vs L			#	#	#	#	#	#	#	#	#	#	#	#	#	#								
M vs V		#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
L vs V																	#	#	#	#	#	#	#	#

Discussion

Order-of-operation and signed number problems are common skills in prealgebra and algebra curriculums. This study suggests that computational gains on these problems using calculators are impressive—algebra scores rose from 43% to 82% to 93% and prealgebra from 20% to 62% to 84% (Manual to LER to MLMO)—and that MLMO calculators provide significant gains over LER calculators. These gains tend to be more pronounced with relatively weaker students (i.e., eighth graders in prealgebra versus those taking algebra) and in problems involving the distributive property.

Although a significant difference exists between LER and MLMO calculators for algebra students, an examination by question suggests that the bulk of the difference—for these students— lies in more complicated problems involving the distributive property and when several rational numbers are involved. For prealgebra students, the differences between MLMO and LER scores are more pronounced, extending over the full range of problems involving the distributive property.

Possible explanations for this phenomena are that eighth graders taking algebra are more able to deal with reduced visual feedback than their counterparts in prealgebra and/or that a better understanding of the concept of distribution facilitates calculator use (particularly with LER calculators). It is hypothesized that more complicated problems—order-of-operation problems with encapsulated brackets (e.g. 3(4-2(5+6))), problems requiring substitutions for variables, problems involving radicals or exponents, and so on—would further exacerbate the advantages of MLMO over LER calculators. The purpose of this study was to investigate points at which such calculators begin to make a difference in the prealgebra/algebra curriculum.

Student reaction to the calculators was pronounced. Prealgebra students who used the MLMO calculators first, followed by the LER model, were particularly vocal in their preference for the MLMO. One student from this group, while using the LER, complained, "You know she (the teacher) has those good (MLMO) calculators in the closet. Why can't we use them?" Another repeatedly got an answer on the LER she knew to be wrong (a simple problem she had worked manually) and complained, "I've put this problem in five times and can't get it to give me the right answer. I'm not going to do it again."

Interestingly, the time taken by students for LER and MLMO calculations was virtually identical. This seems to result from the observation that, unlike the young lady described above, students using LER's rarely re-entered a problem as a check against an answer. Students appeared to look at their calculation on the MLMO screen prior to execution, occasionally changing obvious mistakes.

Concerns and Implications

If calculators are to be used in middle grades to "(a) introduce new concepts, (b) provide a computational tool for use in discovery lessons, (c) simplify the computational aspects of real-life situational problems, and (d) assist students as they solve problems in group learning situations" (Bitter & Hatfield, 1993), then

a calculator that provides better visual feedback—more in keeping with written symbolic notation—and allows students to obtain more accurate answers is of utmost importance. For the students in this study, MLMO calculators were superior tools for basic prealgebra and algebra computations and seem to better fit these purposes than do LER models.

A common concern with calculator use is that students can attain correct answers without understanding the underlying concepts, or without mastering basic pencil-and-paper skills. Several students in this study demonstrated lack of understanding (often writing "don't understand" next to a more complicated problem) or conceptual misconceptions (e.g., $4\_ \times 2\_ = 4 \times 2 + \_ \times \_ = 8\_$) during the manual implementation, yet correctly answered equivalent problems using calculators. How calculators are used in helping students form concepts associated with order-of-operations and signed number operations must receive high priority in instructional planning if calculators are to become instructional tools in addition to computational experts.

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