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ABSTRACT

Presented is a report on a Research and Development program in the use of computer-assisted instruction to teach mathematics in grades 4 through 6. Approximately 60 computer terminals of the PLATO type were installed in elementary school classrooms, 4 terminals per classroom. Each student received one-half hour of mathematics lessons, via computer, each school day, plus whatever instruction the teachers chose to provide. The CAI in question was not the usual sort, using frame-by-frame presentations of content via natural language instruction. Instead, it was based upon the Madison Project strategy of paradigmatic learning experiences, and was presented to students via a computer system having a good audio-visual interface between computer and child. Several independent third-party evaluations of the computer-based curriculum have been carried out. These evaluations indicate positive results for the curriculum in terms of achievement and attitude. (Author/MK)

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ALTERNATIVE USES OF COMPUTERS IN SCHOOLS: COGNITION vs. NATURAL LANGUAGE STATEMENTS[1]

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1. This reports on a fairly large R and D program in the use of computer-assisted instruction to teach mathematics in grades 4 through 6, inclusive.

2. Some details: approximately 60 computer terminals of the PLATO type were installed in elementary-school classrooms, 4 terminals per classroom. Each student received 1/2 hour of mathematics lessons, via computer, each school day, plus whatever instruction the teacher chose to provide. In fact, each teacher continued the "regular" math curriculum from pre-PLATO years, except that a few teachers made adjustments to help relate the "regular" curriculum and the PLATO curriculum.

The PLATO content was arranged in three regular strands, plus one optional strand: a strand in whole-number arithmetic was the most elementary of the strands, and was included (in part) to test the effectiveness of PLATO in dealing with content that schools ordinarily teach successfully. Next more difficult, the *fractions* strand was included (in part) to test the effectiveness of PLATO in dealing with material which schools do NOT usually have much success in teaching. Most advanced of the three regular strands, the *graphs-and-functions* strand was included (in part) to test the effectiveness of material that most schools do not even *attempt* to teach. Finally, for a few students who showed interest, there was instruction in

[1] The R and D effort reported here was supported by Contract No. C-723 from the National Science Foundation.

programming computers; this was considered a fringe benefit, and not part of the official demonstration.

For details of the computer system, in general, see Smith and Sherwood [1976]. Most of the mathematical content had been previously tested with children at this grade level, in face-to-face teaching that did NOT use computers, as part of the Madison Project research [cf. Davis, 1966; Davis, 1980; Davis, 1967].

3. *The main import of this report is that the CAI in question was NOT the usual sort, using frame-by-frame presentations of content via natural-language instruction.*

Instead, it was based upon the Madison Project strategy of PARADIGMATIC LEARNING EXPERIENCES, and was presented to students via a computer system having a good audio-visual interface between computer and child.

a. *Pardigmatic Learning Experiences.*

From 1957 until 1967, The Madison Project - a mathematics "curriculum revision" project housed at Syracuse University and Webster College - carried out studies on the effective teaching of mathematics. Among other things, the project developed a special method of introducing new mathematical ideas to students: *the students were led to engage in an activity that used only competences they already possessed. However, this activity was so designed that it served as an example of the new idea that was to be learned. Activities of this type were called PARADIGMATIC LEARNING EXPERIENCES.*

Examples: i) To introduce negative integers, a student held a bag *partially* filled with pebbles; there was a pile of additional pebbles nearby. To make a definite point in time, a student ("Mary", say) clapped her hands. A problem, 5 - 6 = , (say), was written on the chalkboard. Five pebbles (from the pile) were added to the bag; then 6 pebbles were removed from the bag. The questions now asked were: "Are there more or less pebbles in the bag than there were when Mary clapped her hands?" [Ans: less]. "How many less?" [Ans: one less]. Teacher: O.K. Now we'll write that as $5 - 6 = {}^{-}1$, and we read it as "negative one." It means *one less pebble* than when Mary clapped her hands.

ii) To introduce fractions - say, 1/3 - a student is asked to share something (perhaps building blocks) *fairly* among 3 children. All children seem to have an idea of "fair shares," which can thus be used as a foundation for the idea of fractions. Suppose 12 blocks are shared "fairly" among three children. Each child counts his portion, and the result is written as

$$\frac{1}{3} \text{ of } 12 \text{ is } 4.$$

b. *The Audio-Visual Interface between Student and Computer.*

The PLATO system displays text, diagrams, pictures, or other visual material on what is, in effect, a TV screen (sometimes actually a plasma panel plus rear-view projection). If the student touches this screen, the computer knows when and where the touch occured. A keyset allows a student to "type in" information for the computer. A high-fidelity audio unit allows the computer to present audio material to the student. [Alternatively, a "Votrax" unit provides synthetic speech.] Input and output jacks on the terminal allow other devices to be connected up. (The most popular type deal with presenting music, or inputting and analyzing music. Many of these devices, incidentally, have been invented by high school students.) "Hard-copy" can also be obtained - i.e., whatever appears on the screen can be obtained, if desired, as printed copy on a piece of paper.

To give some idea of the uses of this equipment, we look first at three examples from outside of the realm of mathematics:

i) In a veterinary medicine lesson, a photograph of a dog appears on the screen. If a spot on the dog is touched, the student hears the same sound that he would hear if this were a live dog, and if the student were placing a stethoscope at the spot he has touched.

ii) In a chemistry lesson, the student is asked to carry out a titration. As he controls valves, appropriate flow of fluids is shown on the screen, complete with the possibility of over-filling a vessel and thereby producing a spill, or of shifting pH too far, etc.

iii) Using student-invented equipment, one can play music on a piano-type keyboard; the result is played aloud on a music box, and simultaneously reduced to written notation and displayed on the screen as "instant sheet music".

4. *This report deals with the use of this PLATO computer system, in order to present mathematics lessons - including "paradigmatic learning experiences" - to children in grades 4, 5, and 6, at various public schools in Champaign County, Illinois.*

5. *Design of the Curriculum.*

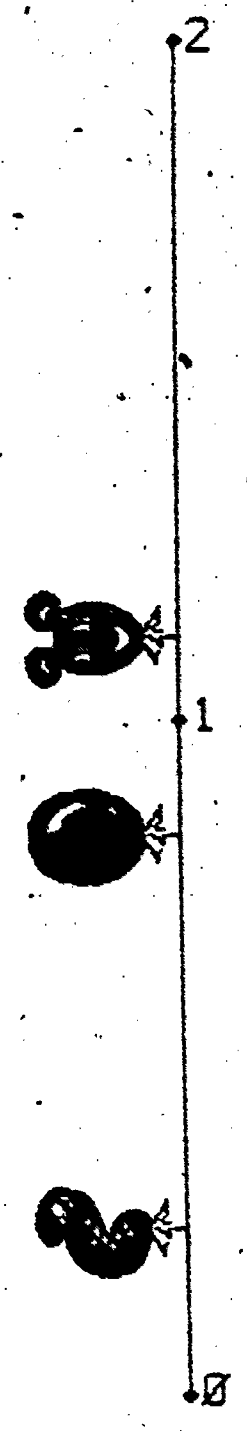
A number of principles guided the design of the curriculum and the design of individual lessons. We mention two:

a. *Meeting Cognitive Needs.*

Extensive use of task-based interviews [e.g.; Erlwanger 1973, 1975] had identified a sizeable collection of cognitive deficiencies in the arithmetical understanding of typical students. As one example, many students had no idea of how *large* .7 is: is .7 larger than 6? Smaller than 6? Larger than 1? Larger than 0? and so on.

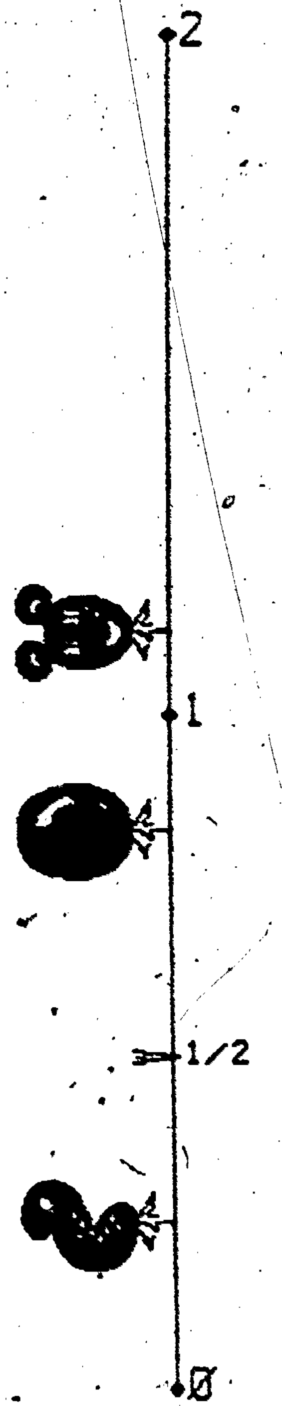
A number of lessons, most designed by Sharon Dugdale, addressed this deficiency. In one lesson, "balloons" are depicted along a vertical number line at the right side of the screen. By typing in a fraction or a decimal, a student causes a "dart" to appear on the left side of the screen, and to move horizontally across the screen. At the right, the dart "thuds" into the wall; if it hits a balloon, the balloon bursts. Since a balloon might be at .75, or at 2 1/3, or elsewhere (actually positioned by random number generation within the computer), a student must have a correct idea of the *size* of fractions, decimals, and mixed-numbers in order to hit the balloons.

[See Figures 1-4]



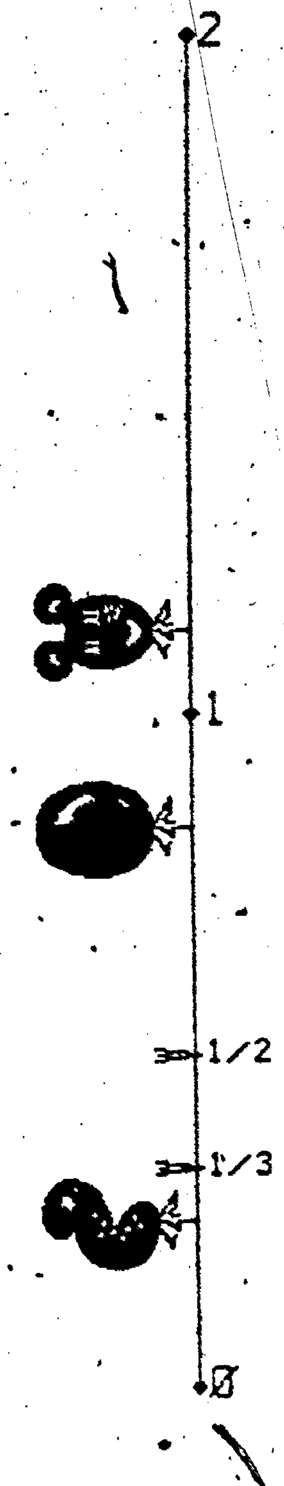
Shoot a dart
at ≫ 1/2

Figure 1 is a reproduction of the display panel, showing 3 balloons positioned on a vertical number line that extends from 0 to 2. The "arrow" ➤ at the lower left asks the student for an input. By typing in 1/2 the student is telling the computer to throw a dart, horizontally, at 1/2 (on the vertical number line).



Shoot a dart
at »

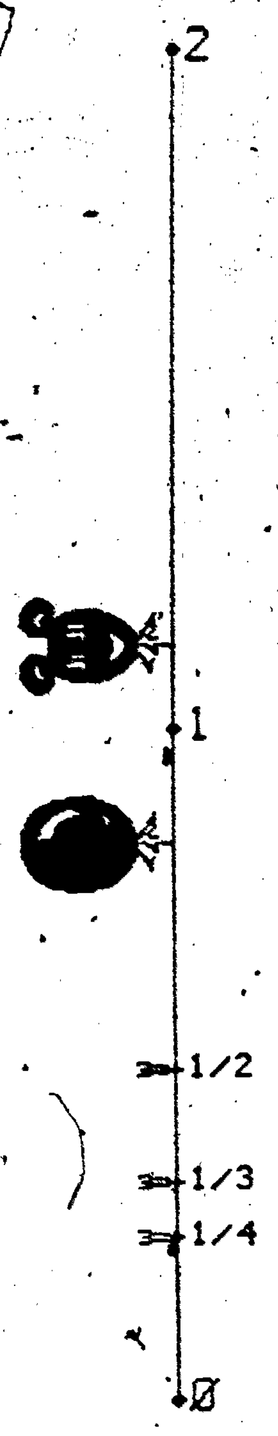
Figure 2 shows the display panel after the computer has "thrown" a dart across the screen, horizontally, at 1/2. The student sees all of this action, but these still pictures only show certain displays, losing the action as still pictures necessarily must. There was no balloon at 1/2, so the dart misses.



Shoot a dart
at ≫ 1/4

Figure 3 shows that 2 darts have been thrown across the screen: one (following the student's directions) has thudded into the "wall" at 1/2, thereby missing; a second dart, thrown at 1/3, has also missed.

By typing 1/4 at the "arrow" ≫ (Lower Left Corner), the student is telling the computer to throw the next dart at 1/4. The computer will carry out this action as soon as the student presses the "NEXT" key.



Shoot a dart
at ≫

Figure 4 shows the dart thrown at 1/4, which has burst one of the balloons. Again, the student sees all of the action, including the bursting of the balloon, but the present still pictures are unable to reproduce the motion of the dart, the bursting of the balloon, etc.

b) *Continuing Classroom Social Activities.*

The presence of the computer should increase, and not decrease, the possibilities of social activities of various sorts. Here is one example: Sue Monell, a teacher in New York City, maintained in her classroom a large appointment calendar. Each day, children could think of an original name for the day's date, and - if no one else had used it already - could write it on the calendar, with their name as "author" or "inventor". Donald Cohen arranged this as an activity on PLATO. Sharon Dugdale made it a "Library Lesson": after devising a new name for today's date (and having it checked for correctness), a student can enter the name into a "Library". Other students can look at the names in this library.

Observation had suggested:

a) students derive gratification from showing their work to other students, to parents, to visitors, etc.;

b) students get many of their ideas from observing other students (plus sometimes deciding to compete with them, to improve on their work, etc.)

Both of these activities are possible via PLATO's "library lessons."

The "Names for Today's Date" library looks, typically, like this [for January 23; only the "23" is used in this exercise; the "author's" name appears beside each entry]:

23+0	Jimmy
23.0	Mary
33-10	Althea
23-0	Katie
23.000	Paul
23+100-100	Randy

$\frac{1}{2}\times 46$	Hiroko
$23\times\cos 0^\circ$	visitor
5^2-2	visitor
$20+3$	Tommy
$19+4$	Susan
$18+5$	Ricky
$10+10+3$	Harold
$20+3$	Lynn

Sharon Dugdale has been able to compare the productions of students before the introduction of "Library" lessons, and afterwards. Students clearly *do* learn from other students (and from "visitors", too!). Whereas pre-library responses are often perfunctory and uninteresting, after "Library" sharing is introduced student work moves rapidly forward, with breakthrough after breakthrough. [Students, for example, soon find that $2^\circ=3^\circ=4^\circ=\ldots=1$, that $3^2=3\times3, 4^2=4\times4, 5^2=5\times5,\ldots$, that $\cos0^\circ=1$ and $\sin0^\circ=0$, that sqrt (25)=5, sqrt(16)=4,... and so on, and begin to use these in their own "names for today's date".]

Putting your work on display, showing it to others, getting ideas from other students are all typical pre-computer classroom activities that can be continued - indeed, enhanced - after the installation of classroom computers.

6. *Summary of Design Considerations.*

a) Clearly, the stethoscopic heart sounds of a dog could not be adequately taught, nor adequately tested, by natural language statements. But this phenomenon is by no means limited to audio signals of a non-verbal sort. A feeling for the *size* of $\frac{5}{7}$, say, can probably be conveyed far better by Dugdale's "darts" game, than by almost any natural language statement.

b) Specific misconceptions among students can be identified, (as in the work of Erlwanger), and lessons can be designed for effective correction (or avoidance) of these misconceptions.

c) Social interactions in classrooms can be observed, and desirable "pre-computer" interactions can be made possible on computers, via appropriate courseware. Desirable sharing of ideas among students is one example.

7. *Evaluation*.

An independent third-party evaluation of this computer-based curriculum has been carried out by Educational Testing Service of Princeton, N.J. Another independent evaluation (using some of the same data) has been carried out by John Gilpin. [Slottow, et al., 1977]

A dozen classrooms of children used the computer lessons, and were matched, student-by-student (on a "matched-pair" basis) with children in classrooms that did not use the computer lessons. A wide range of socio-economic variables were represented among the student population, including also a range of ethnic and racial variables. Various tests were used, but we cite here results on the computations sub-test of the Comprehensive Test of Basic Skills, Level 2, Form R. [For details, see Dugdale and Kibbey, 1977]

During the 1975-76 school year, *grade equivalents* for the students in PLATO and non-PLATO classes were as shown in Table I.

		Fall Administration of CTBS test		Spring Administration of CTBS test		Gain
	N	Mean	S.D.	Mean	S.D.	
PLATO	129	5.0	1.58	6.4	1.70	1.4
non-PLATO	129	5.0	1.62	6.1	1.66	1.1

TABLE I

That is, the addition of the computer lessons shifted the mean gain in G.E. from 1.1 to 1.4 years. (There is less than one chance in a hundred that a difference this large could be due to chance.) The following year the program was continued in these schools, and the gain from fall to spring, averaged over all students using the computer lessons, was 2.0 years (in grade equivalents).

The gains are even more pronounced at the 4th grade level. (At higher grade levels, many students "topped out" on both the courseware and on the tests, so that substantially larger gains in grades 5 and 6 would presumably be possible, given appropriate computer lessons and appropriate tests.) John Gilpin and Sharon Dugdale have devised a method of displaying the year's progress of each individual student; we reproduce in Figure 5 both their data and their arrow display format. Each arrow represents one student: the length of the arrow shows the student's growth (measured in GE by CTBS tests) over one school year.

For our present purposes, we wish to call attention to merely one aspect of the PLATO results: many students proved capable of grade equivalent gains of 3 and 4 years, achieved during one year of school. The attitude data from the PLATO trials are equally positive.

On every single attitude question used, differences strongly favorable to PLATO were observed. [Slottow, et al., 1977]. Pupils were enthusiastic about the mathematics lessons which the computer presented on the TV-like screens, many students sought *extra* sessions, their attitudes toward mathematics improved (as measured by a questionnaire), and so did their attitudes toward their own ability to deal with mathematics. Teacher assessments, though inevitably subjective, were very strongly positive, including even reports that PLATO had decreased anti-social behavior.

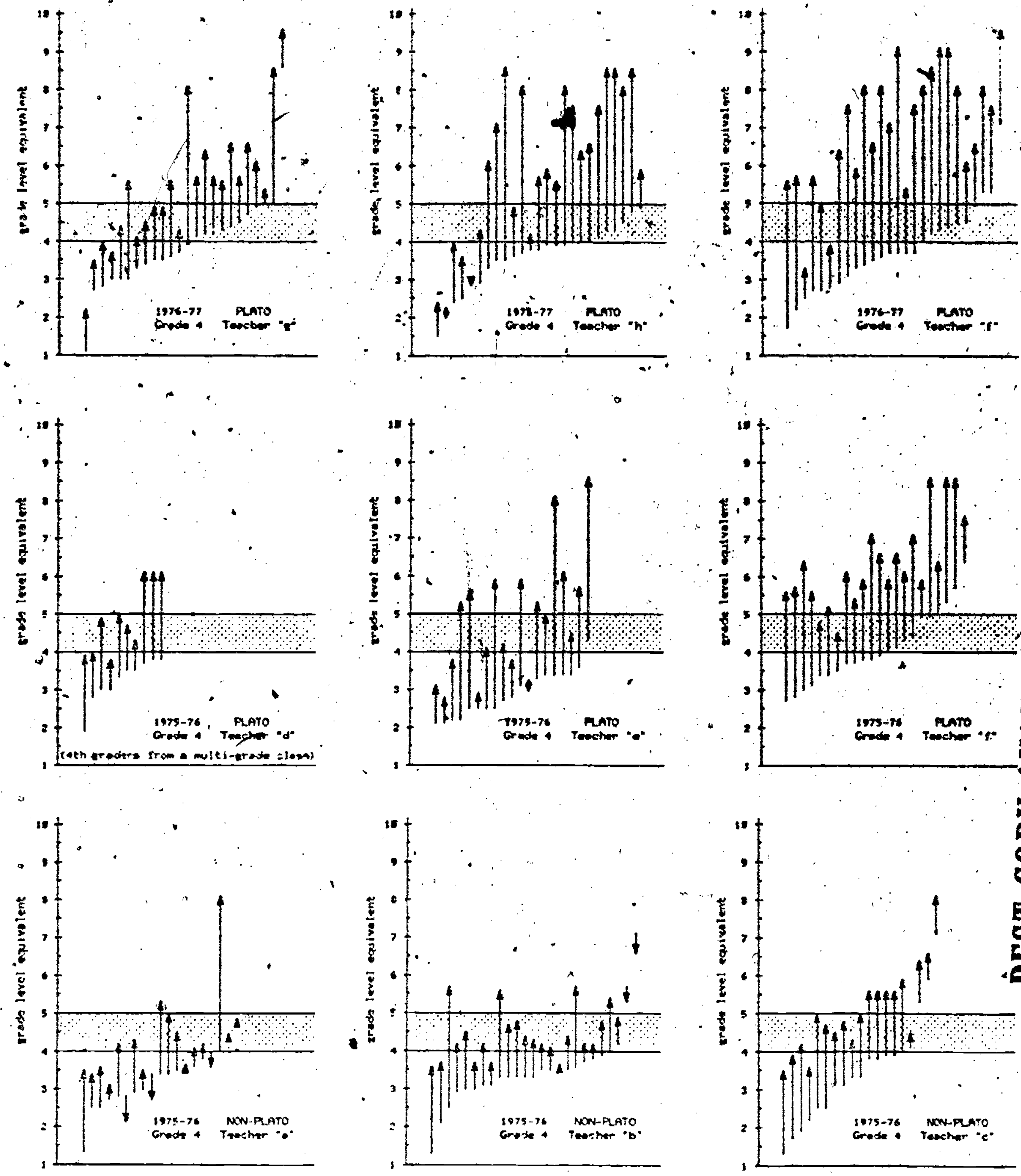


Fig. 5. Changes in arithmetic standing (in grade equivalents) of individuals in PLATO and non-PLATO 4th grade classes. Each vector represents a specific student. The tail of the vector shows the student's grade equivalent on the pretest; the head of the vector shows the student's grade equivalent on the posttest. The shaded area on each graph shows the "expected" growth range of a 4th grade student, from 4.0 to 5.0. The bottom row of graphs corresponds to the 3 non-PLATO classes tested in 1975-76. The middle and top rows are the PLATO classes tested in 1975-76 and 1976-77 respectively. The non-PLATO classes were chosen as comparison classes for the 1975-76 PLATO classes. (No non-PLATO classes were tested in 1976-77.) Teacher "f" taught a PLATO class in each of the two years. PLATO vs. non-PLATO differences have usually shown up most clearly at the 4th grade level. The test used was the Comprehensive Test of Basic Skills, Level 2, Form R, 1968-69 edition.

The evaluation by Swinton, Amarel, and Morgan [1978] is especially thoughtful and painstaking, and should be consulted directly. We present here some of their numerical results, calling attention to the fact that their observations were made one and two years earlier than some of the Gilpin observations; at the time of the first Swinton et al. observations, the PLATO hardware was in its first year, and was unreliable; the courseware, also, was still being developed, and had not yet been revised and improved. An equally careful study nowadays should show much greater gains for the PLATO curriculum.

> Treatment effects were estimated as the difference between observed posttest scores and the scores attained by comparison of children with similar values of covariates (pretest, school, grade, sex, and their interactions). PLATO coverage, reported teacher emphasis, and student characteristics were taken into account in interpreting these results. Significant average treatment effects were found for the following grades and instruments:

Grade 4	CTBS Level 2 Computation	Subtest	+4.77 points	$p < .0011$
	Curriculum-referenced test	Whole Numbers	+2.79 points	$p < .01$
	Curriculum-referenced test	Fractions	+5.36 points	$p < .0001$
Grade 5	CTBS Level 3 Computation	Subtest	+3.42 points	$p < .05$
	CTBS Level 2 Applications	Subtest	+1.21 points	$p < .05$
	Curriculum-referenced test	Fractions	+3.21 points	$p < .01$
	Curriculum-referenced test	Graphs	+2.34 points	$p < .001$
Grade 6	CTBS Level 2 Computation	Subtest	+1.61 points	$p < .05$
	CTBS Level 3 Computation	Subtest	+2.87 points	$p < .05$
	Curriculum-referenced test	Fractions	+2.78 points	$p < .001$
	Curriculum-referenced test	Graphs	+2.16 points	$p < .001$

> Thus, there were significant positive PLATO effects at all grades on a nationally standardized (48-item) test of Computation and on a specially constructed (20-item) test of understanding and representation of fractions, the two higher grades showed significant positive PLATO effects on a test of graphs and linear equations, and grade 4 children exhibited a significant positive treatment effect on a test of understanding of whole number concepts and operations. Such grade-by-treatment interaction is consistent with the level of the strands: the whole number material representing review for many fifth and sixth graders, and the graphs material being quite advanced for many fourth graders. [Swinton, Amarel, and Morgan, 1978]

In their "conclusions" section, Swinton, Amarel, and Morgan report:

> The PLATO Elementary Mathematics Curriculum, in spite or because of its first-draft form and competing teaching philosophies, was a clear success when delivered in an "add on" mode, and was particularly successful when integrated with teacher mathematics coverage.
>
> The mathematics treatment was associated with large achievement gains in grades four through six and with moderate positive attitude outcomes in grades four and five when it was presenting material that was neither overly familiar nor too far above the students' readiness level. The highly structured fractions strand, although sometimes less fun than whole numbers or graphs, was particularly effective in conveying understanding and skills.
>
> A particularly important outcome was revealed in positive effects on instruments designed to measure students' understanding of and ability to represent concepts and operations, beyond mere facility in manipulation of symbols. The PLATO system here demonstrated that it was capable of <u>teaching</u>, as well as of providing drill and practice of concepts already introduced by classroom teachers.
> [Swinton, Amarel, and Morgan, op. cit., pp. 23-4.]

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