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A MICROPROCESSOR-BASED MATHEMATICS
" TRAINER WITH VOICE OUTPUT

By

Michael Joseph Linnig
B. S., University of Louisville, 1978

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A MICROPROCESSOR-BASED MATHEMATIC
TRAINER WITH VOICE OUTPUT

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July 30, 1979
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ABSTRACT

The design and development of a microprocessor-controlled mathematics trainer is described. The trainer is designed primarily for a blind student, and uses synthetic speech to verbally present mathematics problems in the form of incomplete mathematical sentences. The student responds via numeric keypad. Feedback is given to the student immediately after each problem and after each problem session. Several options give the teacher flexibility in pacing the student. In addition, the teacher can create individualized problem sets or choose from many predefined problem sets, arranged in order of difficulty.

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I. INTRODUCTION

Research has shown that, on the average, unsighted students score lower than do sighted students on standardized achievement tests, such as the SAT.¹ Math skill exhibited a definite deficiency.² The area to which this thesis is aimed is that of mathematics and the blind student.

A. The Problem

A blind student is at a disadvantage when compared to the sighted student. The manipulative skills (e.g., scratchwork on paper, problem visualization) that the sighted student routinely employs in working mathematics problems are not as easily employed by the blind student.

Nolan and Ashcroft³ and, more recently, Brothers⁴ reported that blind students average between eight to fifteen percent lower on SAT scores than do sighted students. Brothers⁵ attributes this deficit to the arithmetic computational ability of the blind student. Mathematics skills, therefore, is an area where assistance in training the blind student is strongly needed.

B. Project Motivation

The need for assistance in the area of mathematics training of the blind has been demonstrated above. One device that is currently in use to aid visually handicapped students is the Speech-Plus talking calculator. Originally developed by Telesensory Systems, Inc.,⁶

the talking calculator was later modified by The American Printing House for the Blind to include a speech rate control. A survey of schools using talking calculators⁷ reported the following as frequent applications: teaching number concepts; teaching general and remedial mathematics; and use as a replacement for braille calculators, the abacus, or slide rules for those students who can't or won't use these instruments because they are too cumbersome.

The obvious utility of spoken output prompted the author to pursue the creation of a talking mathematics trainer. Although a braille-output trainer is feasible; only about 21% of visually handicapped students read braille.⁸

C. Some Talking Devices

A review of the appropriate literature revealed no references to a talking mathematics trainer. However, some devices incorporating synthesized speech are worth reviewing.

1. Texas Instruments' "Speak and Spell"⁹

The "Speak and Spell", although teaching a different subject, comes remarkably close to what a mass produced talking math trainer would be like. The "Speak and Spell", selling for only \$48.00 has a vocabulary of about 200 words. The device verbally presents words to be spelled and the user enters answers via an alphabetic keyboard. The "Speak and Spell" also has an alphabetic LED display, used to show the student's entries. The synthesizer used by the "Speak and Spell" is a monolithic device using an advanced linear predictive coding algorithm.

2. The "Speech Plus" Calculator¹⁰

The "Speech Plus" calculator has been mentioned previously. It is a small calculator designed for the blind student. It contains a Read Only Memory (ROM) circuit that stores the speech. The contents of the ROM are clocked out under control of a ROM Controller. The digital speech signal is routed to a resistor network which serves as a digital to analog converter. A more advanced version of the "Speech Plus" synthesizer was chosen as the synthesizer for the Math Trainer.

3. The Votrax¹¹

The Votrax is a phoneme oriented speech synthesizer. With the Votrax, a user can form words by stringing together several basic sounds called phonemes. The use of a phoneme structured device like the Votrax permits an almost unlimited vocabulary. However, each word must be coded by hand, or the phonemes must be chosen by an extremely large program that performs speech synthesis by rule, in order to get a good approximation to human speech.

The aim of the present work is to design and construct a talking mathematics trainer that will assist the visually handicapped student in acquiring basic number skills.

II. FUNCTIONAL SPECIFICATIONS AND MAN-MACHINE INTERFACE

A. Device Overview

A proof-of-concept prototype has been designed to tutor a visually handicapped student in the four basic arithmetic operations: addition, subtraction, multiplication, and division. The device uses speech in order to present the student with an incomplete mathematical sentence such as "three plus two equals blank". The student will use a numeric keypad to enter a choice of what should be in the blank. A sketch of the device is shown in Figs.1 and 2 . The device will inform the student of the response's correctness. If the answer is incorrect, the device will repeat the problem. If the student fails to enter the correct response the second time, the device will inform the student of the response's incorrectness and will speak the entire problem with the correct answer in its proper place. If the student's answer is correct, the device will indicate that the response is correct and speak the complete mathematical sentence with the answer in place. After each problem, the device records the correctness of the student's answer and the amount of time that it took the student to respond. After the student has completed all of the problems that the teacher has assigned, the device reports the number of correct answers, the total number of problems attempted, and the total response time.

The teacher is able to select how the problems will be presented to the student. Problem sets may be setup on the basis of: 1) a maximum

FIGURE 1 Math Trainer

CHOICE OF METHOD
OF DEFINING PROBLEM
SETS ENTERED HERE

FIGURE 2 - Keyboard Detail. Prompt labels are in both print and braille.

total response time, 2) a Power mode, with a fixed number of problems and unlimited time, or 3) a Speed mode where the student has a fixed amount of time per problem and a fixed number of problems in the problem set.

The teacher is also able to define the contents of the problem sets. In addition to specifying the operation involved (addition, etc.), the teacher can delimit the problem sets using two different modes. In one mode, the teacher supplies the device with the level of difficulty desired. In the other mode, the teacher supplies the upper and lower bounds on the two operands needed to define the problems. The problems are generated randomly within a given problem set. The overall sequence of events in the operation of the device is shown in Figure 3. Each problem set is repeatable, so the teacher can determine which type of problem the student finds the most difficult. A discussion of the choices made with regard to problem set generation, as well as learning modes, is presented in the following sections.

B. Problem Generation

1. Range mode

In the Range mode, the teacher defines the problem set by keying in the upper and lower limits for each of the independent variables (OPERANDS) of the problem. The device generates a random number between or equal to, the higher and lower limits for the first operand. This random number then becomes the actual value of the first operand. This process is repeated for the second operand. Once the two operands have been determined, the device will perform

FIGURE 3 Device Flowchart (User's View)

the mathematical operations necessary to solve for the dependent variable.

This mode allows the teacher to tailor problem sets to a student's specific needs. If, for example, a student is having trouble solving problems involving multiplication by three, the teacher could have the device present only problems that have three as the second operand. This could be accomplished by setting both of the limits of the second operand equal to three.

2. Level of Difficulty Mode

In the level of difficulty mode, the teacher supplies a level number to the device; that number corresponds to a specific predefined problem set. Those problem sets are arranged so that, for a given operation, they are progressively more difficult as the level number increases.

The Level mode forms a fixed learning program for the student. The teacher needs only to increment the level number, after the student becomes proficient in the present level, in order to proceed sequentially to the next more difficult problem set. Of course, the teacher must train the student in the mathematical mechanics necessary for each problem set.

In selecting the problem set for each level, every effort was made to present the computational concepts in the same order as is currently employed in the elementary schools.¹² One of the major determinants of problem set difficulty is the presence of problems that involve regrouping. Regrouping is a term used in education to denote the occurrence of a carry in addition or a borrow in subtraction.

The device will discriminate between problems that have regrouping for addition and subtraction. (The problem set definitions for addition and subtraction are shown in TABLES I and II .) Because division is normally taught as the conceptual inverse of multiplication,¹³ it was decided that the division problem sets would be the inverses of the multiplication problem sets (see TABLE III).

C. Problem Presentation

1. Learning Considerations

a. Format. The device is designed to be used by students in elementary school; therefore the problem sets will be limited to integer arithmetic. Generally, non-integer (rational) arithmetic is not introduced to the student until later.¹⁴ Since the integers are not closed under division, only problems that have integer quotients are generated.

It was decided that a signed three digit display would give the device sufficient capability to present the types of problems that are usually taught at the elementary school level.

Often, problems that are presented in the students' textbooks, have the missing number in positions other than to the right of the equals sign. Because of this, the device will allow the teacher to change the position of the missing number to correspond to any of the three positions in the problem sentence.

In teaching machines, one often finds that a student is given a couple of attempts at each problem before being scored incorrect. A good example of the above is Texas Instrument's Speak and Spell, which is a spelling trainer.¹⁵ Given that synthesized speech may be

TABLE I
ADDITION PROBLEM SETS

Problem Set Level	Range of Operands	
	Augend	Addend
1	0 to 4	0 to 4
2	0 to 4	5 to 9
3	5 to 9	0 to 4
4	5 to 9	5 to 9
5	0 to 9	0 to 9
6	0,10,20,...,90	0 to 9
7	0 to 9	0,10,20,...90
8	0,10,20,...90	0,10,20,...90
9*	10 to 99	0 to 9
10*	0 to 9	10 to 9
11	10 to 99	0 to 9
12	0 to 99	10 to 99
13*	19 to 99	10 to 99
14	10 to 99	10 to 99
15*	100 to 499	0 to 9
16*	0 to 9	100 to 499
17	100 to 499	0 to 9
18	0 to 9	100 to 499
19*	100 to 499	10 to 99
20*	10 to 99	100 to 499
21	100 to 499	10 to 99
22	10 to 99	100 to 499
23*	100 to 499	100 to 499
24	199 to 499	100 to 499
25	100 to 499	-499 to 499
26	-499 to 499	100 to 499
27	-499 to 499	-499 to 499

*NOTE: Indicates that problems containing regrouping are not members of the problem set.

TABLE II
SUBTRACTION PROBLEM SETS

Problem Set Level	Range of Operands	
	Minuend	Subtrahend
1*	0 to 4	0 to 4
2*	0 to 4	5 to 9
3*	5 to 9	0 to 4
4*	5 to 9	5 to 9
5*	0 to 9	0 to 9
6**	10 to 99	10 to 99
7	0,10,20,...,90	0 to 9
8	10 to 99	0 to 9
9**	10 to 99	0 to 9
10**	100 to 499	0 to 9
11	100 to 499	0 to 9
12**	100 to 499	10 to 99
13	100 to 499	10 to 99
14**	100 to 499	100 to 499
15	0 to 9	0 to 9
16	19 to 99	10 to 99
17	100 to 499	100 to 499
18	0 to 9	-9 to 9
19	-9 to 9	0 to 9
20	-9 to 9	-9 to 9
21*	-499 to 499	-499 to 499

*NOTE: Indicates the given operand ranges are actually those of the augend and addend in the complementary addition problems.

**NOTE: Indicates that problems containing regrouping are not members of the problem set.

TABLE III
MULTIPLICATION AND DIVISION PROBLEM SETS

Problem Sets Level	Range of Operands *	
	Multiplicand	Multiplier
1	0 to 4	0 to 4
2	0 to 4	0 to 9
3	0 to 9	0 to 4
4	0 to 9	0 to 9
5	0,10,20,...,90	0 to 9
6	0 to 9	0,10,20,...,90
7	0 to 9	10 to 99
8	10 to 99	0 to 9
9	10 to 30	10 to 30
10	0 to 9	-9 to 9
11	-9 to 9	0 to 9
12	-30 to 30	-30 to 30

*NOTE: For division the problem is generated by the multiplication of numbers within the ranges in the table. The product is then placed in dividend position.

difficult to recognize, it was felt that to give the student only one chance per problem would be unduly frustrating. It was decided that the device will give the student two attempts at getting each problem correct.

Without feedback, the student would not be able to learn from making errors. The device provides two forms of feedback. The first is immediate item-by-item feedback. According to Holding, "Separate or item-by-item feedback is very effective in teaching machines".¹⁶ After the student enters an answer, the device immediately informs the student of the answer's correctness. The second type of feedback is what Holding terms "accumulated feedback".¹⁷ In the device, the feedback consists of reporting the number of correct answers, the number of attempted problems, and the total amount of time the student took to answer the problems in the problem set. Holding¹⁸ points out that this type of feedback is especially good for increasing motivation.

One of the skills that is generally taught, alongside the math skills, is the proper speaking of multidigit numbers. Students are taught to pronounce 214 as "two hundred fourteen", and not as "two one four". The decision was made that the device would pronounce its numbers in the proper way.

The device also has the capability to repeat a problem set verbatim. The major use of this feature would be if the teacher noticed that the student had difficulty with the present problem set. The teacher could then cause the problem set to be repeated, and observe the types of problems that give the student the most difficulty.

b. Pacing Options. The teacher may choose three options that govern how the device limits problem sessions. In the first option (the Timed option), the teacher limits the time the student works on a problem set. When the time runs out, the problem session ends. In the second option (Speed), the teacher is able to limit the amount of time per problem attempt, as well as the total number of problems. If the time per attempt runs out, the device acts as if the student had entered an incorrect answer; if the maximum number of problems has been reached the problem session ends. In the third option (Power) the limiting factor is the number of problems. The teacher limits the number of problems in the session, but the student may take any amount of time in responding to each problem. When the maximum number of problems has been completed the problem session ends.

2. Man-Machine Considerations

The foremost feature of this device is that it has a voice output. The Speech Plus talking calculator has been on the market for a few years. The speech synthesizer that is used in the present device is a more advanced version of the one used in that calculator, and has a 64 word fixed vocabulary, shown in TABLE IV.

Using the vocabulary of the synthesizer several standard phrases were created. When a problem has been answered correctly, a string of three low tones (word number 61₁₀) are said by the synthesizer. An incorrect response elicits two high tones (word number 62₁₀). These arbitrary tone sequences were chosen because no semantically relative true-word combinations could be found. The words "go please", however, served nicely as a general purpose audio prompt.

If a sighted student forgets the current problem, that student can simply look at the problem again. A blind student listening to a verbal problem should have the same opportunity. For this reason a repeat problem presentation button has been incorporated into the device.

Because many students are familiar with the Speech Plus calculator, the device's keyboard is designed with the numeric keys in the same configuration as the calculator's. The only difference being the presence of an enter key and a minus key (for negative number entry).

It was also decided to incorporate auditory feedback of keyboard entry into the device. As each key is depressed, the device speaks the key's designation. Keys which do not have descriptions in the vocabulary will, when depressed, cause a tone to be sounded.

In addition to the keyboard echo feature, the device also has a keyboard training drill. This drill will ask the student to depress the keys on the keyboard in a certain order. If the student hits the right key, that key will echo its designation and sound a tone. Wrong keys will only echo their designations. It was decided that the device's display should be as large as possible, so that a low vision student might benefit from the visual input. The main reason for having the display, however, is to aid a sighted teacher in watching the students progress when the student is using headphones.

D. Teacher Programming

Before each problem session, the teacher will have to set up (program) the device in the desired configuration. Parameters such

as pacing mode, operation to be performed, location of missing number, number of problems, level of difficulty, etc. must be supplied to the device. Verbal asking of the required questions is not possible with the limited vocabulary of the device (see TABLE IV). Therefore, a scheme using a prompt beside a written statement (in both braille and print) of the parameter to be entered was decided upon. The prompt is an illuminated LED next to a print and braille label. Later, if funds are available, solenoids will replace the LEDs to allow a non-sighted person to program the device. For details of teacher programming see the users manual in Appendix V. It was felt that, to eliminate student confusion, the programming controls should be located away from the controls the student will use (see Fig. 2). Fig. 4 illustrates the sequence of events involved in setting up the device by the teacher.

TABLE IV

64-WORD SYNTHESIZER VOCABULARY

<u>Data Code (decimal)</u>	<u>Word</u>	<u>Data Code (decimal)</u>	<u>Word</u>
000	zero	032	times
001	one	033	over
002	two	034	equals
003	three	035	point
004	four	036	overflow
005	five	037	clear
006	six	038	percent
007	seven	039	and
008	eight	040	seconds
009	nine	041	degrees
010	ten	042	dollars
011	eleven	043	cents
012	twelve	044	pounds
013	thirteen	045	ounces
014	fourteen	046	total
015	fifteen	047	please
016	sixteen	048	feet
017	seventeen	049	meters
018	eighteen	050	centimeters
019	nineteen	051	volts
020	twenty	052	ohms
021	thirty	053	amps
022	forty	054	hertz
023	fifty	055	DC
024	sixty	056	AC
025	seventy	057	down
026	eighty	058	up
027	ninety	059	go
028	hundred	060	stop
029	thousand	061	tone(low)
030	plus	062	tone(high)
031	minus	063	oh

- 1) Teacher turns device on.
- 2) Teacher chooses either Range or Level mode.
- 3) The Pacing Option (Timed, Speed, Power) is selected.
- 4) If the Time Option was selected the teacher enters the total time limit (via the keypad) in minutes and seconds (up to 99 minutes and 99 seconds).
- 5) If the Speed Option was selected the teacher enters in the time limit per attempt in minutes and seconds (up to 20 minutes).
- 6) If the Timed Option has not been selected the teacher enters the number of problems in the problem session via the keypad.
- 7) The teacher keys in the operation (+, -, x, or $\div$).
- 8) If the Level Mode was selected the teacher keys in the level of difficulty number.
- 9) If the Range Mode was chosen the teacher enters the high and low limits of the first operand followed by the high and low limits of the second operand.

FIGURE 4 - Programming Event Sequence

III. SYSTEM DESIGN

The math trainer, described in Chapter II, consists of a speech synthesizer for voice output, a keyboard for data entry, a visual display for problem presentation, and prompts to aid the teacher in programming problem set information into the device. All of these components are tied together through a controller to form a complete system. The system is designed so that the controller can coordinate the actions of each of the components.

A. System Requirements

The system consists of five basic components; the controller, the keyboard, the LED display, the speech synthesizer, and the prompts. These subsystems are functionally tied together as shown in Fig. 5 .

Specifications for the controller required that it must be able to control the activities of the other components. It must be able to store and manipulate the data received from the keyboard and provide data for the output subsystems (display, synthesizer, and prompts). A microcomputer was the most logical choice for the controller.

The second major component is the keyboard. There are 22 keys on the keyboard; ten digits, minús, enter, repeat, and nine keys dedicated to programming the problem sets. (See Fig.2 in Chapter II). The controller must be able to determine which, if any, of these keys is depressed. The keys themselves must be debounced (i.e., so that a single key closure is not interpreted as multiple closures).

FIGURE 5 - System Overview

The third major subsystem is the LED display, used to present the problem visually. The display must have three numbers, each consisting of a sign and three digits. In addition, it must have an operation sign (+, -, x, ÷) and an equals sign. The display should be as large as possible, as some users will have some useful vision. Moreover, having a large display will allow the teacher to monitor a student's progress from a distance.

The speech synthesizer subsystem is what makes the device unique. The synthesizer must present the problems to the student, echo the keys as they are depressed, provide audio feedback, and report the student's score. The synthesizer must provide intelligible speech at a rate that the user can comprehend.

The last subsystem is the prompt system. This system is designed to say the questions that the synthesizer cannot say, due to its limited vocabulary. If solenoids are eventually used for the prompts, they must be small enough so that if they are placed side-by-side they will not take up too much room in the device. The solenoids must also be rated for continuous duty, low power, and a convenient voltage (five volts would be ideal). At present, small, inexpensive solenoids are not available, so discrete LEDs were substituted. The LEDs must have sufficient brightness to be seen in a normal classroom environment. Use of LEDs instead of solenoids, would not help an unsighted teacher to program the device, but would still allow for proof-of-concept evaluation of the device by blind students.

In addition to the five components described above, the device

must have a DC power supply that is capable of meeting the current and voltage requirements of the subsystems. Also, the device should be portable; therefore, the physical size and weight of the device should be low enough for easy transportation. Although the device is intended as a proof-of-concept prototype, it should, nonetheless, be made as economical as possible.

B. Subsystem Selection

After considering the microcomputer systems that were available, the Motorola 6800 was chosen to act as the controller. A large amount of software is available for the 6800. Also, the 6800 is suited for data manipulation of the type required by the device. For example, it has instructions that perform Binary Coded Decimal (BCD) arithmetic; BCD arithmetic is often used in calculators and devices with large amounts of numeric input and output.¹⁹ Perhaps the most important reason for using the 6800 is its availability. The Perceptual Alternatives Laboratory supplied the author with a Motorola 6800 based D2 evaluation system. That microcomputer is a program development system that allows the programmer to enter, debug, and single step through programs. After development was in progress, the Electrical Engineering Department offered the use of a 6800 based D1 system. It was decided to continue to use the D2 for program development, and to incorporate the simpler D1 into the device as the controller.

The keyboard requires 22 switches; to cut down on the number of switch inputs to the controller, a multiplexing scheme was used.

The switches, themselves, had to be made such that they could be touched without being activated. This feature allows a user to tactually localize the position of the various keys without inadvertently entering incorrect information. Keys that were obtained from a used keyboard satisfy the above condition. These keys were used in the Math Trainer.

For the display, Litronix DL 747²⁰ Seven-segment displays was chosen. These displays (which are common anode) are easily multiplexed. The decision to multiplex the display reduces the number of components required. In addition to the seven-segment displays, an operation display is required. It was decided to make that display from discrete LEDs, since nothing could be found that was suitable for the task.

The next major subsystem is the speech synthesizer. The decision was made to use the Telesensory Systems Incorporated model S2B 64-word voice synthesizer²¹ (see TABLE IV). This synthesizer contains a vocabulary rich enough to be able to say any number up to 999,999 properly. It can also say the words required to present problems. The prompts substitute for most of the additional needed words that are not in the speech board's vocabulary. Words can be added to its vocabulary; but, TSI charges about \$200 to add words available on other models, and considerably more than \$200 for totally new words.²² It was felt that the standard model would be sufficient for a proof-of-concept device. The TSI synthesizer requires 6 word-select lines and two handshake lines. This last subsystem, together with the previously mentioned ones, use up the control lines available on the D1 and D2 computer boards.

The last subsystem is the prompt system. Funds for solenoids were not available, so, LEDs were used instead.

To power the device a Godbout multivoltage power supply was selected. Rated to supply four amps at five volts and 0.5 amps at +12 volts and -12 volts, this supply was chosen for its low cost and availability.

IV. HARDWARE DESIGN

The development of the hardware for the Math Trainer was done in a stepwise fashion. All of the software development was done using a Motorola MEK 6800 D2 kit²³, driving a prototype interface circuit. The prototype interface circuit was constructed on breadboarding sockets. After the majority of the software was completed, the interface circuit was rebuilt in its final form using wire-wrap sockets. Finally, after all of the control programs were finished the software was transferred to EPROMs and a MEK 6800 D1²⁴ board was modified to serve as the controller.

A. The Development System

1. The Controller

The MEK 6800 D2 board (schematic shown in Fig. 1 of Appendix I) was used as the device controller for the Math Trainer during software development. It is well suited to program development. The D2 kit can have as many as 512 bytes of user RAM on board, with provisions for up to 16K bytes of off-board memory. Programs can be entered and changed via a keypad, and an LED display integral to the D2 kit permits verifying contents. Programs may be stored using an audio type recorder. The D2 kit has Peripheral Interface Adapter (PIA) that was used to interface to the Math Trainer's hardware.

2. Memory Expansion

The 512 bytes of on-board RAM available on the D2 kit was quickly found to be insufficient to contain the expanding software.

An expansion memory board, designed by Brian Garvey , was added to the D2 board. (See Fig.6). This memory board can accomodate up to 8K bytes (in 1K increments), of which only 4K bytes were actually installed. The author also designed and installed a memory protect (write disable) circuit to prevent faulty programs from self-destructing. The protect circuit is shown in Fig.7 . A full schematic of the 4K RAM board is shown in Fig.2 of Appendix I .

B. Final System Design

1. The Controller

The D2 kit used for software development was deemed unsuitable for use as the final device controller. Much of D2 would not be needed in the final version (e.g., the cassette interface, the Hex keypad, etc.). A MEK 6800 D1 kit was supplied for the author's use by the Electrical Engineering Department of the University of Louisville and was used as the controller. A schematic of the D1, incorporating the needed changes is shown in Fig.1 of Appendix II.

Unlike the D2, the D1 is a single board computer. It can hold up to 512 bytes of user RAM (although only 256 bytes are required for the controller). Because the user PIA addresses differ for the D1 and D2, the software was changed to reflect that fact before the EPROMs were programmed. The only major changes required to the D1 board involved the RAM select and $\overline{\text{RESET}}$ circuits. The D1's address decoding for the user's RAM is incomplete. When certain parts of the control program are addressed by the microprocessor, user RAM is also selected. Control program range from \$2000 to \$2FFF while user RAM extends from \$0000 through \$00FF. A $\overline{\text{RAM ENABLE}}$ signals was

FIGURE 6 -4K RAM Board

FIGURE 7 - Memory Protect Circuit

generated by OR'ing together A_{15} , A_{14} , A_{13} . This signal was generated on the EPROM board and brought onto the D1 through pin $\overline{E}$. Normally, $\overline{E}$ contains BUS AVAILABLE (BA) but BA was cut where it leaves the microprocessor. A_{15} was cut before reaching the user RAM's. The A_{15} input to two RAM chips was replaced with $\overline{\text{RAM ENABLE}}$ so the RAMs would only be selected if the three most significant address lines were low. The other major change to the D1 involved cutting the output of the on-board reset circuit so that an external $\overline{\text{RESET}}$ signal could be brought in from the edge connector. This circuit along with the other Math Trainer circuits can be found in Appendix II.

A power-on reset circuit was built for the controller utilizing a design shown in the Motorola 6800 Applications Manual²⁵. The actual circuit used is shown in Fig. 8. The user can also reset the device by pushing the normally closed momentary switch (RESTART). That switch interrupts the power to the LM555 causing a power-on sequence.

2. Firmware

A working device cannot store its control programs in RAM, as they would be lost every time power were removed. Control programs must be stored in read only memory (ROM). For the Math Trainer, 2708 erasable programmable ROMs (EPROMs) were used. These EPROMs can be erased and reprogrammed many times.

When the control programs were written, they were located in memory from \$2000 to \$2FFF. The 6800 needs some memory at \$FFFA to \$FFFF for its Reset and Interrupt vectors. It was decided to use incomplete address decoding for the EPROMs, to allow the Restart and Interrupt vectors to be located in the EPROMs. The circuit used

FIGURE 8 - Reset Circuit

for this is shown in Fig. 9 . When the 6800 addresses \$FFFE and \$FFFF to retrieve the Reset vector, the EPROM at \$2FFE and \$2FFF supplies it. In a like way, the Interrupt vector is retrieved.

The EPROMs were programmed under the control of a D2 computer using a PROLOG EPROM Programmer.²⁶ After loading the data to be programmed into the D2's RAM, a program, written by the author and Mr. Jimmy Ryan, was executed. The program sent the data over a RS232 link at 1200 baud to the PROLOG. A diagram showing the circuit used for linking the PROLOG and the D2, and the program appear in Appendix IV.

3. Interface Circuitry

a. Overview. The interface circuitry described in this section includes the LED display, the prompts, the keyboard, the speech synthesizer controls, and the circuitry required to connect those devices to the microprocessor controller. The design used for the Math Trainer needs only one PIA and is shown in Fig.10 . The PIA is divided into two parts, with one part controlling the speech synthesizer and the other part controlling the remainder of the interface. The connections to the synthesizer are straightforward. The busy line is sensed by CA1 and the completion of a word causes an interrupt. The synthesizer is triggered by CA2 (the start line).

The remaining interface is somewhat involved. A four bit device address is sent to a four-to-sixteen-line decoder. The four bit address selects one output device (e.g., 7-segment display, operation sign latch , Prompt latch, etc.) and two input switches. The output data for the displays are contained on the four-bit data

FIGURE 10 - Interface Overview

bus. The positions of the selected pair of switches are sensed by PB0 and PB1. The microprocessor can sequentially output the device addresses and the data to those devices while simultaneously bringing in switch information.

C. Display and Keyboard Circuitry

1. Seven Segment Displays

The Math Trainer requires an LED display for visual problem presentation. Litronix DL 747²⁷ displays were chosen for numeric displays. Multiplexed by the processor, the DL 747s were configured as shown in Fig.11. The 27 ohm resistors were chosen to allow the 7446 to sink as much current as safely possible (40 ma per segment). The low duty cycle (1/16) prevents the average current through the display from exceeding the 30 ma/segment limit.

2. Minus and Equal Signs

The display also contains three minus signs and one equals sign. These signs are constructed using DL 747s in the circuit shown in Fig.11 with the exception that some of the segments are left unconnected. To make a minus sign only segment g (the center bar) is connected. For an equals sign segments a and g are connected into the circuit and the DL 747 is lowered (with respect to the other 7-segment displays) to line up the equals sign.

3. Emergency Blanking Circuit

The average current through the 7-segment displays is within limits as long as the display is multiplexed by the 6800. If the microprocessor halts for some reason, one of the LED displays would be on continuously, thus destroying it. To prevent this a circuit using

FIGURE 11- 7-Segment Display Circuit

half of a LM 556 timer was built (see Fig.12). In this circuit, the timer is set up as a one-shot multivibrator. The 556 triggers when the last device address is selected. The 556's output then goes high, powering the segment driver (7446). The time constant is adjusted so that the 556 times out after 1.5 scan cycles (at 50 cycles/sec). If the display is being multiplexed, the timer is continuously reset and retriggered. If multiplexing stops, the 556 times out and turns off the display driver.

4. Operation Sign

The need for an operation sign (displaying +, -, x, ÷) presented a problem. No commercially available display was both inexpensive and large enough. The author constructed an operation display using discrete LEDs. The LEDs were arranged in a format shown in Fig.13. The discrete LEDs were divided into five groups. To simplify connections, the LEDs within a group (and their current limiting resistors) were tied together as a unit. The way the LEDs were grouped, if one member were on, the remainder of the group should be on (even if they had been wired individually) to display the operation sign properly. The data to the operation sign was latched, rather than multiplexed; the driver circuitry is shown in Fig.14. Only one LED is in group 5 (the center of the matrix), and that LED is wired on continuously, and also serves as a DC power indicator.

5. User Prompts

The teacher has to answer a string of questions to program the Math Trainer. To aid in knowing which question is being asked, a system of LED prompts is used. When an input is required, an LED lights

$$R = 270\text{ k}\Omega$$

$$C = 0.1\mu\text{f}$$

FIGURE 12 - Emergency Blanking Circuit

ADDITION = GROUPS 2,3,4,5
 SUBTRACTION = 3,5
 MULTIPLICATION = 1,5
 DIVISION = 3,4,5

FIGURE 13 - Operation Sign Matrix

FIGURE 14 - Operation Sign Circuitry

up next to a label explaining what information is needed. If the information is to be input to keys other than the keypad keys, an LED lights up below the column of keys to be used. Thus, two sets of LEDs are used: one for the labels and one for the key columns. Within a set, the LEDs are mutually exclusive of one another. Like the operation sign, the prompts are latched and not multiplexed. The prompt latch is located at device address 14_{10} . The prompt circuit is shown in Fig.15 .

6. Interface Summary

The LED display is designed to present arithmetic problems to the user. To do this, it displays three numbers (each consisting of three digits and a minus sign), an operation sign, and an equals sign. The prompt latch, which drives the prompt LEDs to aid device programming by the teacher is also treated as part of the display. (Device address information for the displays appears in TABLE V). The Seven-Segment displays take a BCD code input. In addition, all of the displays (including prompts) interpret an all ones (15_{10}) input as a blanking code. The required driving codes of the other display devices appears in TABLE VI .

FIGURE 15 - Prompt Circuit

TABLE V
DEVICE ADDRESS INFORMATION

Display:

-	1	2	3	÷	-	4	5	6	=	-	5	7	9
---	---	---	---	---	---	---	---	---	---	---	---	---	---

Element: A B C D E F G H I J K L M N

Keyboard:

KEY #	KEY NAME
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
A	minus

KEY #	KEY NAME
B	Range Mode
C	Level Mode
D	Timed Option
E	Speed Option
F	Power Option
10	+
11	-
12	X
13	÷
16	ENTER
17	REPEAT

Device Address Assignment

Device Address	Key #'s	Display Element	Dis. Buf. Ad.
0	0,1	A	\$006
1	2,3	B	\$007
2	4,5	C	\$0008
3	6,7	D	\$0009
4	8,9	F	\$000A
5	A,B	G	\$000B
6	C,D	H	\$000C
7	E,F	*	\$000D

Device Address	Key #'s	Display Element	Dis. Buf. Ad.
8	10,11	K	\$000E
9	12,13	L	\$000F
A	-	M	\$0010
B	16,17	N	\$0011
C	-	E	\$0012
D	-	J	\$0013
E	-	Pro.	\$0014
F	-	-	\$0015

TABLE VI
DISPLAY DEVICE DRIVING CODES

Device Name	Code 8421	Resulting Display	
Minus & equals sign	1000	On	
	1111	Off	
Operations Display	0111	Plus	
	1011	Minus	
	1101	Times	
	1110	Divide	
	1111	Off	
Prompts	0000	Keypad	Prompt On
	0001	Prob. Set	Prompt On
	0010	Pacing Option	Prompt On
	0011	Min:Sec.	Prompt On
	0100	No. of Prob.	Prompt On
	0101	Operation	Prompt On
	0110	Ans. Pos.	Prompt On
	0111	Level	Prompt On
	1000	Hi. Lim.	Prompt On
	1001	Lo. Lim.	Prompt On
	1111	All Prompts Off	

V. SOFTWARE

Currently, the popularity of modular programming is on the rise. Dividing a large program into smaller sections does have advantages. A small section of a program with a single function is easier for a programmer to work with because it is possible to simultaneously grasp all of the interrelationships present. Also, as each module is completed, it can be tested before it becomes part of the larger program.

This modular approach was employed in developing the software for the mathematics trainer. The control program is arranged in an hierarchical structure. At the top of that structure is a program called MAIN. MAIN is a module (or subroutine) that calls upon other modules which perform various functions. These subroutines may also call other subroutines. Generally speaking, anytime a large function was required in a program, the program for that function was broken down into smaller subroutines.

A. Software Development

The only software development tool available was the J-BUG monitor program on the D2 microcomputer.²⁸ The lack of an assembler within JBUG, meant that all programs had to be assembled by hand. Consequently, it was desirable that program changes be performed without having to hand reassemble the code. As a result of this, program corrections were made by using patches. A patch is branch from the normal path, to the program correction, followed by a branch

back to the original path. As programs develop, their sizes change. With limited memory, these size changes require that subroutine locations be shifted to efficiently utilize the limited memory space. Any shifting of subroutine locations would normally require that the program be reassembled; however, the use of relative branching and Link (a programming technique) prevents this.

Any discussion of the device's software must be prefaced by a description of the internal architecture of the 6800 microprocessor. The 6800 has three internal data storage register; a 16-bit index register (x-reg.), and two eight-bit accumulators (the A and B registers). The index register is often used as a pointer to address locations in memory. In addition there are three registers whose presence is somewhat invisible to the programmer: the condition code register (contains the carry bit, overflow bit, etc.), the stack pointer (keeps track of the information in the stack, a LIFO buffer), and the program counter (points to the location of the next instruction).

B. The Software

The software can be divided into four major functional divisions: control routines, input/output routines, arithmetic routines, and special function routines.

Control subroutines act as high level administrators of the device's operations. As various functions need to be performed, the control routines call the needed subroutines. For example, in the teaching mode, TEACH is the control program; it would call GENERATE (to set up the next problem), GETANS (To solve for the answer), and SAYDISP (to say the problem). For a glossary of the control routines

and the other routines see TABLE VII.

The next major functional subdivision involves the transferring of information to and from the various input/output devices. Because the trainer requires simultaneous display output and keyboard input, a single routine had to be able to perform both input and output functions; that routine is SCAN. The information to be output by SCAN is stored in two buffers, the speech buffer (SPKBUF) and the display buffer (DISBUF). The other I/O routines either load information into the buffers (e.g., DISPLAY and SPKWD) or call SCAN repeatedly to bring in a series of keystrokes (e.g., GETDIG).

The third major division of the software is the arithmetic routine division. The 6800 microprocessor is limited in the types of arithmetic functions it can perform. To overcome these limitations and to eliminate repetition of instruction sequences, various arithmetic subroutines were created. To supplement the 6800's instruction set, double-byte binary addition and subtraction subroutines (DADD and BISUB) were added to the programming repertoire.

It was decided that BCD arithmetic should be used in generating the problems. The motivation to use BCD representation stemmed from a need to do manipulations upon various digits of the number (when checking for regrouping, for example) that would be difficult to perform if the numbers were in a binary format. The BCD format employed is a 2-byte representation, with the sign bit occupying the most significant bit of the high order byte. The hundreds digit is contained in the low nibble of the high order byte. The low order byte contains the ten's and one's digits in the high and low nibbles, respectively.

Various subroutines were written in order to perform BCD arithmetic. BCDADD does simple unsigned additions, and ADDEM uses BCDADD to do signed BCD addition. Signed BCD multiplications are performed using BCDMULT. In solving for the answers to the problems created by GENERATE, GETANS calls various BCD subroutines. Magnitude comparisons of BCD numbers can be done by using HI-LO and COMPARE. To generate random numbers, a subroutine (RANDOM) was developed using an 11 stage linear-feedback shift register, realized in software.

The last major software division covers the subroutines that are labeled as special function subroutines. Those routines result from modularizing the control routines. The subroutines RIGHT and ERROR are called by TEACH to signal correct and incorrect student answers. They could have been built into TEACH, but having them separate allowed TEACH to be a simpler module. In a similar way, RESTART is the initializing module for MAIN. Anytime a reset occurs, RESTART is called and, in turn, calls MAIN.

A glossary of subroutines is shown in TABLE VII, and the calling hierarchy of those routines is shown in TABLE I of Appendix III. A functional description of the subroutines follows, with first level subroutine calls identified. The commented disassembled listing of the entire program is shown in Appendix III.

1. Control Subroutines

These subroutines form the control structure of the math trainer's software.

a. MAIN Program. MAIN orchestrates the sequencing of the device's functions (see Fig. 16). The order of the functions

TABLE VII

GLOSSARY OF SUBROUTINES, ARRANGED BY FUNCTIONAL DIVISION

Control Subroutines

DRILL - trains the student to use the keyboard.

MAIN - sequences the calling of the other control routines.

PROGRAM - allows the teacher to define the problem set via the keyboard.

REPORT - gives information on the student's performance on the current problem session.

TEACH - presents problems to the student and keeps track of the student's performance.

Input/Output Subroutines

- BLANK - erases the contents of the LED display buffer.
- BLANKIT - erases the missing number from the LED display buffer.
- DISPLAY - puts the present problem, including the answer, into the LED display.
- GETDIG - retrieves up to 6 digits from the keyboard while outputting the contents of the speech and display buffers.
- GETEM - prompts for input and calls GETDIG to retrieve digits.
- LDPAUS - loads a variable length pause (up to five seconds) into the speech buffer.
- PACK - takes three digits and the sum entered via the keyboard and compresses them into a two-byte signed BCD number.
- SAYDISP - takes a two-byte number and loads the words needed to say it into the speech buffer.
- SCAN - outputs the contents of the display and speech buffers until a single key is pressed or a pre-specified amount of time has passed. This is the routine that actually performs all of the I/O operations.
- SPKEY - loads the name of the pressed key into the speech buffer (used for echoing entries).
- SPKWD - loads the word in the A-register into the speech buffer.
- UNPACK - takes a signed two-byte BCD number and expands it and stores it in the display buffer.
- WAIT - holds up program execution while outputting display and speech buffer contents. Execution is delayed until WAIT empties the speech buffer.

Arithmetic Subroutines

ADDEM - performs two-byte signed BCD addition.

BCDADD - performs two-byte unsigned BCD addition.

BCDINC - (BCD) increments the contents of two memory locations.

BCDMULT - performs signed BCD multiplication.

BISUB - performs two-byte binary subtraction.

COMPARE - performs two-byte signed BCD comparison.

DADD - performs two-byte binary addition.

GETANS- solves for answer to problem.

HI-LO - determines if random number is between two limits.

RANDOM - generates a signed three digit random decimal number.

Special Function Subroutines

ERROR - causes the display to blink and an error tone sequence to be sounded.

GENERATE - randomly picks the numbers for a problem within limits provided by the teacher.

INTERRUPT - is called by an interrupt when the speech synthesizer has finished saying a word.

LINK - allows easy program relocation.

LOADX - allows parameter passing.

MINTOBI - converts data entered as minutes and seconds to binary seconds.

OPGEN - randomly picks a single number (when in the level of difficulty mode) using the definition supplied by TBLOOK (see below).

RIGHT - causes a tone sequence indicating correct to be sounded.

RESTART - initializes the math trainer on power up or when the reset button is pressed.

SAYNUM - loads the correct pronunciation of a three digit number into the speech buffer.

TBLOOK - looks up the problem set definition from the level of difficulty supplied by the teacher.

2BEEP - loads the words "GO PLEASE" into the speech buffer.

FIGURE 16 -MAIN Subroutine

called by MAIN are: PROGRAM (allows the teacher to define the problem set), DRILL (the user's keyboard training drill), TEACH (the subroutine that presents the problems), and REPORT (the subroutine that reports on the student's performance). In addition, MAIN insures that the seeds used for the random number generator (used to randomly generate problems) are not equal. The problem set definitions are looked up by TBLLOOK when the machine is in the Level of Difficulty mode. An entire problem set can be repeated by pushing the repeat button after the report has been given.

b. DRILL Subroutine. DRILL is a keyboard familiarization drill for the student. The device says N-"please" via SPKEY, where N is the name of a key (see Fig.17). The student then attempts to push the named key. If the student doesn't push the named key, the pushed key's name is echoed and, after a pause, the key is again requested. If the student does press the correct key, the key name is echoed and a tone is sounded. DRILL then proceeds to the next key, and sequentially steps through the keys, zero to nine, and then the minus key.

c. PROGRAM SUBROUTINE. The PROGRAM subroutine shown in Fig. 18 prompts the teacher to enter the information that determines which problems are to be presented and how those problems are to be presented. In addition, PROGRAM also generates the random number seeds which are used for generating random problems by counting the number of scans that take place before the teacher responds. Information entered under control of PROGRAM, is then used by the TEACH subroutine, which presents the selected problems to the student.

FIGURE 17 -DRILL Subroutine

FIGURE 18 - Program Subroutine

FIGURE 18 - Continued

FIGURE 18 - Continued

d. REPORT Subroutine. The REPORT subroutine reports how well the student performed on the last problem set. The total number of correct problems, the number of problems attempted, and the total amount of time spent by the student are reported both visually (in the LED display) and vocally (via the synthesizer). The flowchart of REPORT appears in Fig. 19.

e. TEACH subroutine. The TEACH subroutine quizzes the student on arithmetic problems. TEACH presents the problem using the LED display and the voice synthesizer. The student's answer is entered via the keyboard. Two attempts to correctly answer the problem are permitted. If the answer is incorrect, two high tones are sounded and the display blinks. If the student's answer is correct, three low tones are produced by the synthesizer. Also, if the answer was correct or if two incorrect attempts have been made, TEACH will present both the problem and the correct answer to the student, in the form of a complete mathematical sentence.

TEACH keeps track of the number of questions that the student has been asked, the number of problems missed, and the total amount of time the student has used to solve the problems.

Depending on the option that is selected by the teacher, TEACH presents the problems in different ways (see Fig.20). If the timed option is selected, the student has a fixed amount of time in which to work as many problems as possible. There is no fixed limit on the amount of time that can be spent on one given problem. If the speed option has been chosen, the student has a fixed amount of time for each attempt and a prescribed number of problems to do. The power option

FIGURE 19 - REPORT Subroutine

FIGURE 20 - TEACH Subroutine

FIGURE 20 - Continued

specifies that the student has a fixed number of problems to solve and an unlimited amount of time in which to do them.

2. Input/Output Subroutines

These routines control the information flow between the display, keyboard, and speech synthesizer via the microprocessor-controller.

a. BLANK Subroutine. BLANK (shown in Fig.21) stores a blank (FF_{16}) in all of the locations of the display buffer. The effect of BLANK is to turn off the display while SCAN is executed.

b. BLANKIT Subroutine. BLANKIT, which is shown in Fig.22, blanks the missing number in the display buffer. If a problem is to be displayed without the answer appearing on the LED's, the routine DISPLAY would be called to put the entire display into the buffer and BLANKIT would be called to blank the answer.

c. DISPLAY Subroutine. DISPLAY calls UNPACK to load the contents of NUM1, NUM2, and NUM3 into the corresponding display buffers (see Fig.23). The buffers for the equal sign and the operation sign are also loaded with their proper values. Leading zeros in the display are blanked by storing a blanking code (FF) in place of the zeros.

d. GETDIG Subroutine. GETDIG, shown in Fig.24, is used whenever a multidigit number is needed from the keyboard. GETDIG is entered with the time limit (in scans) stored in the X register (like SCAN). GETDIG returns when the time limit is exhausted, or if six digits have been entered. Pushing the enter key also causes a return from GETDIG. The entered digits are stored in a push down stack consisting of DIG1 through DIG6. The last digit entered is always stored at DIG1, and previous entries are pushed down toward DIG6. The total

FIGURE 21 - BLANK Subroutine

FIGURE 22-BLANKIT Subroutine

FIGURE 23 - DISPLAY Subroutine

FIGURE 24 - GETDIG Subroutine

FIGURE 24 -Continued

number of digits entered is stored in SGNDIG. Pushing the minus key causes the sign bit (bit 7) of SGNDIG to be set. Pushing the repeat button causes a call to SAYDISP, and GETDIG is restarted (clearing any entered digits).

e. GETEM Subroutine. GETEM (see Fig.25) is a general purpose prompt and keyboard entry subroutine. The contents of the A-register are stored in the prompt buffer. GETEM then causes the words "GO PLEASE" to be loaded into the speech buffer. A call to GETDIG brings in up to 6 digits from the keyboard (see Fig. 24).

f. PACK Subroutine. PACK takes the information received from the keyboard by GETDIG and compacts it into a two-byte packed BCD number at the memory location addressed by X and X+1 (see Fig.25).

g. SAYDISP Subroutine. SAYDISP is the routine that loads the present problem into the speech buffer. Depending on the value of the variable SAY, one of three things will happen: 1) if SAY is equal to zero then SAYDISP will return with no action having been taken, 2) if SAY is equal to one, SAYDISP will load the problem into the buffer with a low tone in place of the missing number and 3) if SAY is equal to two, the entire problem including the missing number, is loaded into the speech buffer. The flowchart for SAYDISP is shown in Fig.26.

h. SCAN Subroutine. SCAN is the routine that controls all of the input and output functions for the device; it performs the keyboard scanning for input data, and multiplexes the data to the LED display. The desired number of SCANS (at 50 scans/sec) is stored in the X-register before calling SCAN. When SCAN is called, the

FIGURE 25 - GETEM and PACK Subroutines

FIGURE 26 - SAYDISP Subroutine

information stored in the display buffer (DISBUF) is routed to the display. SCAN also controls the speech synthesizer. Data stored in the speech buffer (SPKBUF) is sent to the synthesizer, one word at a time, until the speech buffer is empty. SCAN continues execution until one of two things happen: 1) if the desired number of scans has been completed, SCAN will return; and 2) depressing and releasing a key on the keyboard will cause a return from SCAN.

SCAN is divided into four major segments: SCAN DISPLAY, CHECK SPEECH, CHECK TIME, and KEY DEBOUNCE, that are executed sequentially.

SCAN DISPLAY controls the LED display and the keyboard. The display, shown in Fig.10, plus the prompts are divided into 15 parts, each with its own four-bit device address. Corresponding to each device address is an output buffer location (in DISBUF). Also, each device address selects two keys as inputs. SCAN DISPLAY outputs the device addresses along with the data stored in DISBUF, and brings in the key information. A total is kept in SUM of the number of keys down simultaneously, if any. Also, the key number is stored in KEY (see Fig.27). After SCAN DISPLAY has output to all 15 device addresses, control is passed on to CHECK SPEECH.

CHECK SPEECH, shown in Fig.28, drives the TSI speech synthesizer. The synthesizer has 8 signal lines: six input data lines, one start line, and one busy status output line. When the start line is brought to the low state, the synthesizer begins saying the word selected by the six data lines. While the synthesizer is saying a word, its busy line is held in the low state. When the word is finished the busy

FIGURE 27 - SCAN DISPLAY Subroutine

line returns to the high state and causes an interrupt reentry to CHECK SPEECH.

CHECK SPEECH stores the data that is to be output to the synthesizer in a software FIFO (first-in, first-out buffer). The FIFO is organized as a circular buffer. Fig. 29 illustrates that buffer in two states, before and after data wrap around. Two pointers are used in this buffer; NEXT and LAST. NEXT always points to the next word in the buffer that is to be output. LAST Points to the location beyond the newest data word. When a new word is loaded into the buffer it is stored where LAST points and then LAST is incremented. In a similar way, when the word pointed to by NEXT has been spoken, NEXT is incremented by CHECK SPEECH to point to the next word in the buffer. If NEXT is incremented beyond the top of the buffer, it is set equal to the address at the bottom of the buffer. When NEXT equals LAST the buffer is empty.

The data in the buffer is of two types; words and pauses. A word is data that is destined to be routed to synthesizer. The six most significant bits of the word are sent to the synthesizer over the six data lines. The two least significant bits of a word must be zeros. If the two least significant bits of the buffer data are not zero, then the data is assumed to be a pause. A pause is an eight bit number representing the number of scans that should lapse before the next word is spoken. The maximum pause length is 2^8-1 or 255 scans. At 50 scans per second the maximum PAUSE is 5.1 seconds.

When the device is initialized, the start line is set to its high state and NEXT and LAST are set equal. If SCAN is called at this point, the fact that NEXT equals LAST tells CHECK SPEECH that the

Circular FIFO Buffer before Data wrap around

Circular FIFO Buffer after Data wrap around

FIGURE 29 - Circular FIFO (Speech Buffer)

buffer is empty, and the rest of CHECK SPEECH is bypassed (see Fig.28). When data has been stored in the buffer and SCAN is called, CHECK SPEECH is not bypassed. On the first pass through CHECK SPEECH, the data pointed to by NEXT is stored in the variable PAUSE if it is a pause and NEXT is INCREMENTED. If the data is a word to be spoken, it is put on the six data lines to the synthesizer and the PAUSE register is set to one. Further passes through CHECK SPEECH only decrements the PAUSE register. When the PAUSE register has been decremented to zero, and the data pointed to by NEXT is present on the data lines, CHECK SPEECH brings the start line from high to low. This triggers the synthesizer to begin saying the word. CHECK SPEECH also increments the value of NEXT, pointing it at the next data item. While the start line is low, CHECK SPEECH is bypassed. After the synthesizer has finished saying the word, it brings the busy line high, which causes an interrupt. The INTERRUPT routine brings the start line high, enabling CHECK SPEECH.

The buffer is 32 bytes long. It was felt that this length was large enough that the author would not have to be concerned about the program overflowing it. Also, having the audio output stored in a queue allows the device to simultaneously output speech, output to the LED display, and bring in key information.

The third major segment of SCAN is CHECK TIME. When SCAN is called, the number in the X-register is stored in SCNTIM. Normally, on each pass through CHECK TIME, SCNTIM is decremented. This occurs only if SCNTIM is not equal to its maximum value $65,535_{10}$ (or $FFFF$ in hexadecimal). When SCNTIM has been decremented to zero, a return is

performed and the computer exits SCAN. The maximum amount of time in SCAN is 21.84 minutes (65,535 scans). However, if SCAN is called with the X-register containing $\$FFFF_{16}$, SCAN will not automatically time out (see Figs. 30 and 31).

The KEY DEBOUNCE portion of SCAN takes the information provided by SCAN DISPLAY and uses it to determine when a key has been pushed and released. For a key to be valid, it must be held down for two scans of the keyboard and then released. If more than one key is depressed, then the keys are ignored. This technique of debouncing is often used in calculators.²⁹ KEY DEBOUNCE is a software emulation of a finite state machine (see Figs. 30 and 31). When a key is released KEY DEBOUNCE causes a RTS to be executed.

i. SPKEY Subroutine. The SPKEY subroutine interprets the data in the A-register as a key number. If the key has a corresponding word in the synthesizer's vocabulary, that word is loaded into the speech buffer; otherwise, a high tone is loaded into the speech buffer (see Fig. 32). The keys that have corresponding words are zero through nine and the minus key.

j. SPKWD and LDPAUS Subroutines. SPKWD and LDPAUS are the subroutines that load data into the speech buffer. SPKWD is the routine that is used to load a word, stored in the A-register, into the buffer. LDPAUS takes the number in the A-register and stores it in the buffer. The routine calling LDPAUS must insure that one of the two least significant bits is a one, if SCAN is to interpret the number as a pause. After the data is inserted into the buffer, at the location pointed to by LAST, LAST is incremented so that it points to the

FIGURE 30 - CHECK TIME & KEY DEBOUNCE Subroutine

FIGURE 31- Finite State and Key Debounce

FIGURE 32 - SPKEY Subroutine

next empty buffer location (see Fig.33).

k. UNPACK Subroutine. Decimal numbers, internal to the device, are stored in packed BCD format of the form:

[SXXX, hunds]:[tens, ones]

high byte low byte

where [] is a byte,

S is a sign bit (1 implies minus),

X is a don't care bit,

hunds is the hundreds digit,

tens is the tens digit,

ones is the units digit.

UNPACK takes the number stored in A:B and puts this data, one digit per byte, into four bytes starting at the memory location addressed by the X-register. Because the routine is used to load the display buffer, the digits are stored in the high nibbles of the unpacked data bytes (see Fig.34).

l. WAIT Subroutine. WAIT performs a function very similar to its name. WAIT continues to SCAN the display and output words to synthesizer until the speech buffer is empty. WAIT holds up program execution while the speech buffer is being emptied; it prevents the speech from getting too far behind the programs that generate the speech (see Fig.35).

3. Arithmetic Subroutines

These routines perform the necessary background computations to generate problems for the student.

FIGURE 33 - SPKWD and LDPAUS Subroutines

FIGURE 34 -UNPACK Subroutine

FIGURE 35 - WAIT Subroutine

a. ADDEM Subroutine. ADDEM is a signed BCD addition routine. It adds the signed BCD numbers in UNE and DEUX and places the result in TROIX.

ADDEM uses 10's complement arithmetic to add negative numbers (see Fig.36). If one of the numbers is negative, the 10's complement of that number is formed. The numbers are then added. If the result is negative, the ten's complement of the answer is taken and the sign bit is set.

b. BCDADD Subroutine. The BCDADD subroutine takes the two-byte BCD data word stored in A:B and decimal adds it to the contents of the location addressed by the X-register (see Fig.37).

c. BCDINC Subroutine. The BCDINC subroutine loads A:B with one and jumps to BCDADD. The net effect is to increment (BCD) the contents of the locations addressed by the X-register (see Fig.38).

d. BCDMULT Subroutine. BCDMULT is a signed BCD multiplication routine. The two numbers to be multiplied are in stored in packed BCD notation. The numbers are located in the double byte variables NUM1 and NUM2 and the result is stored in NUM3. NUM1 and NUM2 are not destroyed in the multiplication process. BCDMULT requires that NUM1 and NUM2 be between -99 and +99, and the resulting product must lie in the range of -999 to +999. A flow chart of BCDMULT appears in Fig. 39.

e. BISUB Subroutine. The BISUB subroutine is a general purpose double byte binary subtraction routine. When called, it subtracts the number in A:B from the number addressed by X and X+1 (see Fig. 40).

FIGURE 36 - ADDEM Subroutine

FIGURE 37 - BCDADD Subroutine

FIGURE 38 - BCDINC Subroutine

FIGURE 39 - BCMULT Subroutine

f. COMPARE Subroutine. The need to be able to compare signed BCD numbers prompted the writing of COMPARE. COMPARE subtracts the number in the X-register from the variable VALUE using signed BCD arithmetic. The result is returned in the X-register (see Fig.41). Branching can be reliably done using the Z and N bits in the condition code register.

g. DADD Subroutine. DADD is a double byte binary addition routine. DADD adds the contents of A:B to the contents of the memory locations addressed by X and X+1. (See Fig.42).

h. GETANS Subroutine. GETANS is the routine that finds the answer to the problem defined by NUM1, NUM2, and OPSIGN. If, for example, OPSIGN was multiplication, then GETANS would call BCDMULT to find the product of NUM1 and NUM2 (see Fig.43). The result of the multiplication would be stored in NUM3.

GETANS doesn't always perform the operation suggested by OPSIGN. If OPSIGN corresponds to division, GETANS will multiply the contents of NUM1 and NUM2. The resulting product is moved to NUM1 and the original NUM1 and NUM2 are moved to NUM2 and NUM3 respectively. These moves correspond to forming the complementary division problem of the multiplication of NUM1 times NUM2.

Normally, subtraction is accomplished in GETANS by reversing the sign of the second number, and adding the two operands. However, if MODE corresponds to Level of Difficulty and bit 14 of PROBTYP (called the T-bit) is set, then subtraction is done by adding NUM1 and NUM2. The sum is stored at NUM1 and the original NUM1 and NUM2 are moved to NUM2 and NUM3, respectively. This

FIGURE 40 - COMPARE Subroutine

FIGURE 41 - BISUB Subroutine

FIGURE 42 - DADD Subroutine

FIGURE 43 - GETANS Subroutine

produces the complementary subtraction problem to the problem, NUM1 plus NUM2.

i. HI-LO Subroutine. HI-LO compares the contents of VALUE and the upper and lower bounds imbedded in the code of the calling routine (see Figs. 44 and 45); if VALUE is between the limits then the carry bit is set, otherwise it is cleared.

HI-LO calls LOADX to retrieve the inline data and to increase the return address stored on the stack so that when the RTS instruction is executed, the program counter points to the next instruction in the calling routine, and not to the data. HI-LO calls COMPARE to determine if VALUE is between the limits.

j. RANDOM Subroutine. The RANDOM subroutine generates a random number using the two byte seed addressed by the X-register. The new seed is stored at the two memory locations addressed by X. The resulting random number is stored in the two byte variable VALUE.

The seed is treated as a linear feedback shift register. The seed is shifted left and the new bit zero is formed by Exclusive OR'ing the previous bit zero and bit ten together (see Fig.46). This feedback register has a period of $2^{11}-1(=2045)$.³⁰ The seed is Exclusive OR'ed with a mask to further randomize the number. The random number is then converted from binary to decimal and stored in VALUE.

4. Special Function Subroutines

This section contains the descriptions of subroutines that perform special functions for the control subroutines.

FIGURE 44 - How HI-LO Works

FIGURE 45 - HI-LO Subroutine

FIGURE 46 - RANDOM Subroutine

a. ERROR Subroutine. The ERROR subroutine causes the display to blink several times and the speech synthesizer to output two high tones (see Fig.47). ERROR is used as negative feedback by TEACH when the student enters an incorrect answer.

b. GENERATE Subroutine. The GENERATE subroutine, using the information provided by the teacher, randomly chooses the values of the two operands, NUM1 and NUM2. In the level of difficulty mode, GENERATE calls OPGEN to obtain the values for NUM1 and NUM2. Also, if regrouping is not allowed, GENERATE insures that is is not present in the problem (see Fig.48). If the Range mode is selected, GENERATE insures that NUM1 is between HILIM1 and LOLIM1, and that NUM2 is between HILIM2 and LOLIM2.

c. INTERRUPT Program. When the speech synthesizer is through talking, its Busy lines goes low, and imitates an interrupt. When an interrupt is received, the interrupt program sets the synthesizer's start line to its high state (see Fig.49) and thereby informs SCAN that the synthesizer has completed talking. After the interrupt has been serviced, the computer resumes what it was doing previously.

d. LINK. LINK is neither a program nor a subroutine. LINK provides a way of tying together all of the subroutines used in the device. All subroutine calls are passed by jump statements in LINK to the called subroutines. This allows a subroutine to be moved in memory with very little trouble. Normally, when a subroutine is moved, all of the calls to that subroutine must be changed. With LINK all of the calls to a particular subroutine actually call a jump statement in LINK; the jump statement then transfers control to the called

FIGURE 47 - ERROR Subroutine

FIGURE 48 - GENERATE Subroutine

FIGURE 49 - INTERRUPT Subroutine

subroutine. Thus, when the called routine is moved, only the jump address in LINK must be changed.

e. LOADX Subroutine. LOADX passes parameters from a primary routine to a secondary routine. The two byte parameter is embedded in the primary routine immediately after the call to the secondary routine (Figs. 50 and 51). . The secondary routine calls LOADX, which loads the parameter into the X-register. LOADX also adjust the primary routine's return address located on the stack, so that a RTS in the secondary routine causes a return to the primary routine beyond the parameter. LOADX preserves the values of registers A and B by storing them on the stack.

f. MINTOBI Subroutine. The MINTOBI subroutine derives its name from MINutes TO BInary. This subroutine assumes that GETDIG has been called previously and that a number of the form, [tens of minutes, unit minutes, tens of seconds, unit seconds], has been entered. MINTOBI converts this data to binary seconds and stores it at the two memory locations addressed by the X-register (see Fig.52). MINTOBI does this by multiplying the digits 1 through 4 by weighting factors.

g. OPGEN Subroutine. The OPGEN subroutine generates a random number within a certain range. This range varies with the contents of the A-register when OPGEN is called (see TABLE VII). The Seed used for the random number is stored at the memory locations addressed by the X-register when OPGEN is called.

OPGEN calls RANDOM to generate the random number (see Fig.53). The number is then adjusted to fit the limits defined by A (i.e. if the

FIGURE 50 - How `LOADX` Works

FIGURE 51 - LOADX Subroutine

FIGURE 52 - MINTOBI Subroutine

TABLE VIII
 OPERAND RANGE AS DEFINED BY A-REGISTER

<u>Contents of A(hex)</u>	<u>Range of Operand</u>
0	0 to +4
1	-4 to +4
2	+5 to +9
3	-9 to -5 and +5 to +9
4	0 to +9
5	-9 to +9
6	0, 10, 20, ..., 90
7	-90, -80, -70, ..., 70, 80, 90
8	+10 to +99
9	-99 to -10 and +10 to +99
A	-99 to +99
B	+100 to +499
C	-499 to -100 and +100 to +499
D	-499 to +499
E	Same as D
F	Same as D

FIGURE 53 - OPGEN Subroutine

number is defined as two digits ,then the third digit is blanked).

If the number is still outside the defined limits, another random number is generated and the limits are checked again.

h. RIGHT Subroutine. The RIGHT subroutine is used by TEACH as positive feedback for the student. When called, RIGHT turns off the prompt and sounds a low tone three times. A flowchart of RIGHT appears in Fig. 54 .

i. RESTART Program. The RESTART program is called on device power-up or when the reset button is pushed. RESTART initializes the PIA's and it initializes the variable that controls scan speed (RATE), the display buffer (DISBUF), the pointers for the speech buffer (NEXT and LAST) (see Fig.55). The processor's stack pointer is also initialized to its starting position at \$00FF. After RESTART is executed, control is passed to MAIN.

j. SAYNUM Subroutine. The SAYNUM subroutine takes the number addressed by the X-register and says it. The number is assumed to have the following two byte format:

[SXXX, hundreds]:[tens, ones]

at (X)† at (X+1)†

where; S is the sign bit (set implies minus)

Z is a "don't care" bit

hundreds, tens, and ones are stored in

BCD notation

FIGURE 54 - RIGHT Subroutine

FIGURE 55 -RESTART Subroutine

(See Figure 56 for the exact algorithm used to say the number).

SAYNUM says the numbers as the students are taught to say them. For example, -327 is pronounced as "minus three hundred twenty-seven," not as "minus three two seven."

k. TBL00K Subroutine. TBL00K is the subroutine that looks up the problem set information when the device is in the Level of Difficulty mode. The problem set information is contained in three different tables. If the operation is addition, then the problem set information is in ADDTBL. If the operation is subtraction then SUBTBL contains the information. Multiplication and division information is stored in M-DTBL. All of the tables end with the flag \$FFFF. If the level of difficulty exceeds the number of problem sets (and the flag is found), TBL00K will cause the device to restart (see Fig. 57).

l. 2BEEP Subroutine. The 2BEEP subroutine is an audio prompting subroutine. Originally call 2BEEP would cause two "hi tones" to be sounded, hence its name. 2BEEP was changed so that calling it causes the words "Go Please" to be loaded into the speech buffer (see Fig.58).

FIGURE 56 - SAYNUM Subroutine

FIGURE 57 - TBLOOK Subroutine

FIGURE 58 - 2BEEP Subroutine

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Cost Analysis

The Math Trainer was designed to be a proof-of-concept prototype. As such, it was not designed to be mass produced in its present form. This version is too expensive to be marketable in reasonable quantity. After evaluating the device's usefulness and implementing any necessary changes, use of production oriented technology could render it more marketable. A breakdown of costs for the components of the device is shown in TABLE IX. Not shown in TABLE XI are the development costs and the cost of the labor required to assemble the device.

B. Device Improvement Recommendations

The Math Trainer works as it was designed to. The lack of funds to install solenoids as prompts has left the device somewhat difficult, but not impossible, for a blind teacher to program. If such funds become available in the future, the installation of solenoids is highly recommended.

It was noted that some users find the order of programming questions unnatural. Rearranging the question order would be a simple matter and, as such, may be desirable. If PROGRAM were to be rewritten, a useful addition would be to implement error checking of the numeric inputs (preventing negative numbers entered as a position, for example). The trainer could be made more compact by using a CMOS microprocessr and a single voltage 4K EPROM. Doing that

TABLE IX
DEVICE COSTS

Speech Synthesizer.....	\$189.00
Support Circuits for Synthesizer.....	70.00
D1 Microcomputer.....	75.00
(4) 2708 EPROMS.....	48.00
Cabinet for Device.....	100.00
Power Supply.....	50.00
(13) DL747 LED Displays.....	13.00
Keyboard Components.....	15.00
Miscellaneous Electronic Components.....	75.00
Miscellaneous Hardware.....	40.00
TOTAL COST	\$675.00

would allow the bulky multi-voltage supply to be replaced by a much smaller power supply.

Currently, the device is slated to be evaluated by using it at the Kentucky School for the Blind in the Fall of 1979. Some changes may be suggested by that evaluation.

C. Notes on Doing Similar Projects

Several things became apparent while working on the Math Trainer. The creation of the device at the assembly language level made the device difficult to change. Any feedback from users was difficult to take advantage of due to the difficulty of changing existing programs. Anyone working on a similar project would be prudent to insure that the man-machine interface design was finalized before writing the control software. For some projects, a high level language program (e.g. in BASIC) could be written to simulate the device. Changes could be easily made to the simulation program in response to user feedback. These changes could then be incorporated into the machine language control program from the beginning. The use of a "Tiny Basic" may even allow the final control program to be written in a high level language.

An assembler would also be a great aid in producing control programs. Although an assembler was made available to the author it was not used because most of the software was written by the time the assembler was obtained. A great deal of time was spent by the author debugging incorrectly hand-assembled programs.

One resource that was not taken full advantage of was the extensive amount of arithmetic software already written for the 6800. The author's experience indicates that it would be worthwhile to use some of this available software even if some data conversion were required.

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APPENDIX I
DEVELOPMENT CIRCUITRY

FIGURE 1 - D2 Board Microcomputer Module

FIGURE 1 - D2 Board Microcomputer Module (continued)

FIGURE 1 - D2 Display Module

FIGURE 1 - D2 Display Module (continued)

FIGURE 2 - 4K RAM Board

FIGURE 3 - Memory Protect Circuit

APPENDIX II
DEVICE HARDWARE DOCUMENTATION

FIGURE 1 - D1 Board with Changes

FIGURE 1 - Continued

FIGURE 2 - Display Board (Section 1)

FIGURE 2 - Display Board Section 2 (LED Display)

FIGURE 2 - Display Board Section 3 (Prompts)

FIGURE 2 - Display Board Section 4 (Operation Sign)

FIGURE 2 - Display Board Section 5 (Front View)

FIGURE 3 - EPROM Board (Back View)

FIGURE 4 - Keyboard (Back View)

FIGURE 5 - Jumper Board (Back View)

FIGURE 6 - Power Supply

TABLE I
CONNECTOR INFORMATION

Connector C1 maps directly to pins on C7.
 Connector C2 maps directly to pins on C8.
 Connector C3 maps directly to pins on C9.
 Connector C5 maps directly to pins on C6.

CONNECTOR C7

Pins 4 through 11 are GND.
 Other pins not connected.

CONNECTOR C8

Pin 1 = C11,1	Pin 8 = C10,2
2 = C11,13	9 = C10,13
3 = C11,2	10 = C10,6
4 = C11,12	11 = C10,9
5 = C11,3	12 = C10,5
6 = C11,11	13 = C10,10
7 = C11,4	14 = C10,4

CONNECTOR C9

Pin 1 = +5v	Pin 8 = C10,11
2 = +5v	9 = C10,3
3 = +5v	10 = C10,12
4 = +5v	11 = +5v
5 = C10,8	12 = +5v
6 = C10,7	13 = +5v
7 = C11,14	14 = Not Connected

CONNECTOR C4

Pin 1 = Pin 9 on SPEECH BOX	Pin 8 = Pin 1 on SPEECH BOX
2 = Pin 10 on SPEECH BOX	9 = Pin 2 on SPEECH BOX
3 = Pin 11 on SPEECH BOX	10 = Pin 3 on SPEECH BOX
4 = Pin 12 on SPEECH BOX	11 Not Connected
5 = Pin 13 on SPEECH BOX	12 Not Connected
6 = Pin 14 on SPEECH BOX	13 Not Connected
7 = Pin 15 on SPEECH BOX	14 Not Connected

EPROM CONNECTOR

U
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P
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M
L
K
J
H
F
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D
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B
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13
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15
16
17
18
19
20
21
22

PIA CONNECTOR

Pin 38
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25

D1 CONNECTOR

10
40
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39
38
 $\overline{T}$
 $\overline{S}$
37
36
 $\overline{R}$
 $\overline{P}$
35
34
 $\overline{N}$
 $\overline{M}$
33
 $\overline{E}$
N/C
N/C
N/C
RESTART SWITCH
1,2,3,A,B,C
5
W,X,Y,41,42,43
N/C
 $\overline{J}$
 $\overline{L}$
30
32
 $\overline{H}$
 $\overline{K}$
29
31

CONNECTED TO

C10,13
C10,2
C10,12
C10,3
C10,11
C10,4
C10,10
C10,5
C10,9
C10,6
C10,8
C10,7
C11,14
C11,1

PIA CONNECTOR

Pin 24
 23
 22
 21
 20
 19

CONNECTED TO

C11,13
C11, 2
C11,12
C11,3
C11,11
C11,4

APPENDIX III

SOFTWARE DOCUMENTATION

These listings were produced by using a disassembler program on a D2 microcomputer. The disassembled listings, output by the D2, were transferred to the University of Louisville's DEC-10 computer via a digital cassette recorder. Using the DEC-10's text editors (SOS and TECO), comments and symbolic addresses were added. The listings were printed on a DEC-WRITER. The SOS editor was also used to generate the subroutine hierarchy listings.

TABLE I

SYMBOL TABLE

Stack starts at \$00FF

PIA Addresses

\$8008 = PORT-A
 \$8009 = CONT-A
 \$800A = PORT-B
 \$880B = CONT-B

RAM Addresses

\$0000 = KEY
 \$0001 = BF
 \$0002 = DADDR
 \$0003 = SUM
 \$0004-04 = XSAV
 \$0006-15 = DISBUF
 \$0016-17 = NEXT
 \$0018-19 = LAST
 \$001A-1B = SCNTIM
 \$001C = PAUSE
 \$001D-3C(32 bytes)=SPKBUF
 \$003D = SGNDIG
 \$003E-43 = DIG1-DIG6
 \$0044-45 = TIMER
 \$0047-47 = RATE
 \$0048 = MODE
 \$0049 = OPTION
 \$004A-4B = SEED 1
 \$004C-4D = TIMLIM
 \$004E-4F = MAX PROBS
 \$0050 = OPSIGN
 \$0051-52 = MISSING #
 \$0053-54 = HILIM1/LEVEL
 \$0055-56 = PROBTYP/LOLIM1
 \$0057-58 = HILIM2
 \$0059-5A = LOLIM1
 \$005B-5C = NUM1
 \$005D-5E = NUM2
 \$005F-60 = NUM3
 \$0061 = SAY
 \$0062-63 = SEED 2
 \$0064-65 = ATTPROBS
 \$0066-67 = WRONG
 \$0068-69 = SECONDS

\$006A-6B = MINUTES
 \$006C = ERROR
 \$006D-6E = DISPTIME
 \$006F-70 = ANSWER
 \$0071-72 = BINSECS
 \$0075-76 = VALUE
 \$0077-78 = UNE
 \$0079-7A = DEUX
 \$007B-7C = TROIX
 \$007D-7E = SEED A
 \$007F-80 = SEED B
 \$0081-82 = ADDRESS

ROM MEMORY ADDRESS

\$2000-2026 = RESTART(1)
 \$2027-202F = INTERRUPT
 \$2030-2045 = RESTART(2)
 \$2046-2081 = MAIN
 \$209F-20FC = RANDOM
 \$20FD-2112 = BCDTBL
 \$211D-21C9 = OPGEN
 \$21CA-21E4 = HI-LO
 \$2200-222F = DOWN(utility)
 \$2240-228F = DISPLAY
 \$2290-22BF = UP(utility)
 \$22C7-22D5 = BCDADD
 \$22D6-22DA = BCDINC
 \$22DC-22F3 = LOADX
 \$22F4-241D = PROGRAM
 \$2455-2467 = 2BEEP
 \$2469-24A6 = MINTOBI
 \$24A7-24FF = SAYNUM
 \$2500-25FD = SCAN
 \$2600-2611 = SPKWD and LDPAUS
 \$2612-261D = GETEM
 \$2620-262F = SPKEY
 \$2634-2670 = DRILL
 \$2680-268C = WAIT
 \$268D-2702 = GETDIG
 \$2710-272F = BLANKIT
 \$2730-2748 = UNPACK
 \$274A-2798 = SAYDISP
 \$279A-2810 = LINK
 \$281A-2868 = BCDMULT
 \$2869-28FF = GETANS
 \$291C-2922 = BISUB
 \$2924-2935 = COMPARE
 \$2936-2A3A = GENERATE
 \$2A43-2ABD = REPORT
 \$2ABE-2BE3 = TEACH
 \$2C00-2C3A = ERROR

\$2C40-2CB9 = ADDEM
\$2CBF-2CC7 = DADD
\$2CCF-2D16 = TBLOOK
\$2E00-2E3A = ADDTBL
\$2E80-2EA8 = SUBTBL
\$2F10-2F19 = M-DTBL
\$2F70-2F7F = BLANK
\$2FAB-2FC8 = PACK
\$2F80-2F96 = RIGHT
\$2FF8-2FFF = RESTART AND INTERRUPT VECTORS

TABLE II
SUBROUTINE HIERARCHY

```

*****
****      6800 CONTROL PROGRAM FOR TEACHING MACHINE      ****
****      BY MICHAEL J. LINNIG      MAY 1979      ****
*****
**** START OF RESTART PROGRAM ****
2024 7E 2030      JMP      $2030
**** START OF INTERRUPT PROGRAM ****
**** END OF INTERRUPT PROGRAM ****
**** START OF RESTART (2) PROGRAM ****
**** END OF RESTART (2) ****
**** START OF MAIN PROGRAM ****
2046 BD 27D2      JSR      PROGRAM      * TEACHER DEFINES PROB. SETS
2049 BD 27ED      JSR      DRILL        * KEYBOARD TRAINING DRILL
205E BD 27A0      JSR      TBLOOK      * LOOK UP PROBLEM SET INFO
2064 BD 279A      JSR      TEACH       * TEACH MATH PROBLEMS
206A BD 27FC      JSR      REPORT      * GIVE TOTAL RIGHT & TIME
206D BD 27C6      JSR      BLANK       * BLANK ENTIRE DISPLAY
2072 BD 27F6      JSR      SPKWD       * LOAD WORD INTO SPEECH BUF.
2078 BD 27F9      JSR      SCAN        * INPUT:KEYS  OUTPUT:DISP. & TALK
2081 7E 204C      JMP      $204C
**** END OF MAIN ****
**** START OF RANDOM SUBROUTINE ****
20E8 BD 27B4      JSR      BCDADD      * ADD A:B TO LOC @ X
**** START OF BCDTBL LOOK UP TABLE ****
**** END OF BCDTBL ****

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**** START OF UPGEN SUBROUTINE ****
2131 BD 27AC      JSR    RANDOM      * RANDOM NUMBER GENERATOR
2134 BD 27FF      JSR    HI-LO      * SET C IF VALUE BETWEEN LIMITS
2162 BD 27FF      JSR    HI-LO      * SET C IF VALUE BETWEEN LIMITS
2191 BD 27FF      JSR    HI-LO      * SET C IF VALUE BETWEEN LIMITS
21A6 BD 27FF      JSR    HI-LO      * SET C IF VALUE BETWEEN LIMITS
**** START OF HI-LO SUBROUTINE ****
21CA BD 2802      JSR    LOADX      * LOAD X FROM INLINE DATA
21CD BD 279D      JSR    COMPARE     * COMPARE (BCD) VALUE & X
21D4 BD 2802      JSR    LOADX      * LOAD X FROM INLINE DATA
21D9 BD 2802      JSR    LOADX      * LOAD X FROM INLINE DATA
21DC BD 279D      JSR    COMPARE     * COMPARE (BCD) VALUE & X
**** START OF DOWN UTILITY PROGRAM ****
**** START OF DISPLAY SUBROUTINE ****
224B BD 27CC      JSR    UNPACK      * SEPERATE NIBBLES INTO BYTES
2255 BD 27CC      JSR    UNPACK      * SEPERATE NIBBLES INTO BYTES
225F BD 27CC      JSR    UNPACK      * SEPERATE NIBBLES INTO BYTES
**** START OF UP UTILITY PROGRAM ****
**** START OF BCDADD SUBROUTINE ****
**** START OF BCDINC SUBROUTINE ****
22D9 7E 27B4      JMP     BCDADD      * ADD A:B TO LOC @ X
**** START OF LOADX SUBROUTINE ****
**** START OF PROGRAM SUBROUTINE ****
230B BD 27E1      JSR    2BEEP      * SAY "GO PLEASE"
2311 BD 27F9      JSR    SCAN       * INPUT:KEYS  OUTPUT:DISP. & TALK
2316 BD 27F0      JSR    SPKEY      * ECHO KEY NAME
232D BD 27E1      JSR    2BEEP      * SAY "GO PLEASE"
2333 BD 27F9      JSR    SCAN       * INPUT:KEYS  OUTPUT:DISP. & TALK
2338 BD 27F0      JSR    SPKEY      * ECHO KEY NAME
2356 BD 27E1      JSR    2BEEP      * SAY "GO PLEASE"
235C BD 27E7      JSR    GETDIG     * GO GET DIGITS FROM KEYBOARD

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2362	BD	27DE	JSR	MINTOBI	* CONVERT MMM:SS TO BIN. SECS
237E	BD	27D8	JSR	DADD	* TWO BYTE BINARY ADD
2397	BD	27E1	JSR	2BEEP	* SAY "GO PLEASE"
239D	BD	27E7	JSR	GETDIG	* GO GET DIGITS FROM KEYBOARD
23A3	BD	27DB	JSR	PACK	* PACK MULTIDIGIT INFO
23AA	BD	27E1	JSR	2BEEP	* SAY "GO PLEASE"
23B0	BD	27F9	JSR	SCAN	* INPUT:KEYS OUTPUT:DISP. & TALK
23B5	BD	27F0	JSR	SPKEY	* ECHO KEY NAME
23C8	BD	27E1	JSR	2BEEP	* SAY "GO PLEASE"
23CE	BD	27E7	JSR	GETDIG	* GO GET DIGITS FROM KEYBOARD
23D4	BD	27DB	JSR	PACK	* PACK MULTIDIGIT INFO
23E1	BD	27E1	JSR	2BEEP	* SAY "GO PLEASE"
23E7	BD	27E7	JSR	GETDIG	* GO GET DIGITS FROM KEYBOARD
23ED	BD	27DB	JSR	PACK	* PACK MULTIDIGIT INFO
23F3	BD	27D5	JSR	GETEM	* PROMPT & SCAN FOR RESPONSE
23F9	BD	27DB	JSR	PACK	* PACK MULTIDIGIT INFO
23FE	BD	27D5	JSR	GETEM	* PROMPT & SCAN FOR RESPONSE
2404	BD	27DB	JSR	PACK	* PACK MULTIDIGIT INFO
2409	BD	27D5	JSR	GETEM	* PROMPT & SCAN FOR RESPONSE
240F	BD	27DB	JSR	PACK	* PACK MULTIDIGIT INFO
2414	BD	27D5	JSR	GETEM	* PROMPT & SCAN FOR RESPONSE
241A	BD	27DB	JSR	PACK	* PACK MULTIDIGIT INFO
**** START OF 2BEEP SUBROUTINE ****					
2455	BD	27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
245A	BD	27F3	JSR	LDPAUS	* LOAD PAUSE INTO SPEECH BUF.
245F	BD	27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2464	BD	27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
**** START OF MINTOBI SUBROUTINE ****					
246B	BD	27D8	JSR	DADD	* TWO BYTE BINARY ADD

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2480 BD 27D8      JSR      DADD          * TWO BYTE BINARY ADD
2490 BD 27D8      JSR      DADD          * TWO BYTE BINARY ADD
**** START OF SAYNUM SUBROUTINE ****
24B1 BD 27F6      JSR      SPKWD         * LOAD WORD INTO SPEECH BUF.
24B9 BD 27F6      JSR      SPKWD         * LOAD WORD INTO SPEECH BUF.
24BE BD 27F6      JSR      SPKWD         * LOAD WORD INTO SPEECH BUF.
24C3 BD 27F3      JSR      LDPAUS        * LOAD PAUSE INTO SPEECH BUF.
24D4 BD 27F6      JSR      SPKWD         * LOAD WORD INTO SPEECH BUF.
24E2 BD 27F6      JSR      SPKWD         * LOAD WORD INTO SPEECH BUF.
24EC BD 27F6      JSR      SPKWD         * LOAD WORD INTO SPEECH BUF.
24F7 BD 27F6      JSR      SPKWD         * LOAD WORD INTO SPEECH BUF.
**** START OF SCAN SUBROUTINE ****
**** START OF CHECK SPEECH ROUTINE ****
**** START OF CHECK TIME ROUTINE ****
**** START OF KEY DEBOUNCE ROUTINE ****
25FB 7E 27E4      JMP      CONTINUE      * MAKE ANOTHER SCAN
**** START OF SPKWD AND LDPAUS SUBROUTINES ****
**** START OF GETEM SUBROUTINE ****
2614 BD 27E1      JSR      2BEEP         * SAY "GO PLEASE"
261A BD 27E7      JSR      GETDIG        * GO GET DIGITS FROM KEYBOARD
**** START OF SPKEY SUBROUTINE ****
2628 BD 27F6      JSR      SPKWD         * LOAD WORD INTO SPEECH BUF.
**** START OF DRILL SUBROUTINE ****
263A BD 27F0      JSR      SPKEY         * ECHO KEY NAME
263F BD 27F6      JSR      SPKWD         * LOAD WORD INTO SPEECH BUF.
2645 BD 27F9      JSR      SCAN          * INPUT:KEYS  OUTPUT:DISP. & TALK
2650 BD 27F0      JSR      SPKEY         * ECHO KEY NAME
2653 BD 27EA      JSR      WAIT          * WAIT TILL SPEECH-BUF EMPTY
265C BD 27F6      JSR      SPKWD         * LOAD WORD INTO SPEECH BUF.
2661 BD 27F3      JSR      LDPAUS        * LOAD PAUSE INTO SPEECH BUF.
**** START OF WAIT SUBROUTINE ****
2683 BD 27F9      JSR      SCAN          * INPUT:KEYS  OUTPUT:DISP. & TALK
**** START OF GETDIG SUBROUTINE ****

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269C	BD 27F7	JSR	SCAN	* INPUT:KEYS OUTPUT:DISP. & TALK
26E4	BD 27F0	JSR	SPKEY	* ECHO KEY NAMES
26EF	BD 27C0	JSR	SAYDISP	* PRONOUNCE PROBLEM
26F2	BD 27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
26FC	BD 27E1	JSR	2BEEP	* SAY "GO PLEASE"
**** START OF BLANKIT SUBROUTINE ****				
**** START OF UNPACK SUBROUTINE ****				
**** START OF SAYDISP SUBROUTINE ****				
275A	BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2766	BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2772	BD 27F3	JSR	LDPAUS	* LOAD PAUSE INTO SPEECH BUF.
2786	BD 27CF	JSR	SAYNUM	* PRONOUNCE PACKED NUM AT (X)
278C	BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2792	BD 27F3	JSR	LDPAUS	* LOAD PAUSE INTO SPEECH BUF.
**** START OF LINK ****				
279A	7E 2ABE	JMP	\$2ABE	* TO TEACH
279D	7E 2924	JMP	\$2924	* TO COMPARE
27A0	7E 2CCF	JMP	\$2CCF	* TO TBLOOK
27A3	7E 2869	JMP	\$2869	* TO GETANS
27A6	7E 2C40	JMP	\$2C40	* TO ADDEM
27A9	7E 281A	JMP	\$281A	* TO BCDMULT
27AC	7E 209F	JMP	\$209F	* TO RANDOM
27B1	7E 2936	JMP	\$2936	* TO GENERATE

27B4	7E	22C7	JMP	\$22C7	* TO BCDADD
27B7	7E	22D6	JMP	\$22D6	* TO BCDINC
27BA	7E	2C00	JMP	\$2C00	* TO ERROR
27BD	7E	291C	JMP	\$291C	* TO BISUB
27C0	7E	274A	JMP	\$274A	* TO SAYDISP
27C3	7E	2710	JMP	\$2710	* TO BLANKIT
27C6	7E	2670	JMP	\$2F70	* TO BLANK
27C9	7E	2240	JMP	\$2240	* TO DISPLAY
27CC	7E	2730	JMP	\$2730	* TO UNPACK
27CF	7E	24A7	JMP	\$24A7	* TO SAYNUM
27D2	7E	22F4	JMP	\$22F4	* TO PROGRAM
27D5	7E	2612	JMP	\$2612	* TO GETEM
27D8	7E	2CBF	JMP	\$2CBF	* TO DADD
27DB	7E	28DB	JMP	\$2FAB	* TO PACK
27DE	7E	2469	JMP	\$2469	* TO MINTOBI
27E1	7E	2455	JMP	\$2455	* TO 2BEEP
27E4	7E	2509	JMP	\$2509	* TO CONTINUE (LOCATED IN SCAN)
27E7	7E	268D	JMP	\$268D	* TO GETDIG
27EA	7E	2680	JMP	\$2680	* TO WAIT
27ED	7E	2634	JMP	\$2634	* TO DRILL
27F0	7E	2620	JMP	\$2620	* TO SPKEY
27F3	7E	2602	JMP	\$2602	* TO LDPAUS (LOCATED IN SPKWD)

27F6	7E	2600	JMP	\$2600	* TO SPKWD (SEE LDPAUS)
27F9	7E	2500	JMP	\$2500	* TO SCAN (SEE CONTINUE)
27FC	7E	2A43	JMP	\$2A43	* TO REPORT
27FF	7E	21CA	JMP	\$21CA	* TO HI-LO
2802	7E	22DC	JMP	\$22DC	* TO LOADX
2805	7E	2F80	JMP	\$2F80	* TO RIGHT
2808	7E	211D	JMP	\$211D	* TO OPGEN
**** START OF BCDMULT SUBROUTINE ****					
2861	BD	27B4	JSR	BCDADD	* ADD A:B TO LOC @ X
**** START OF GETANS SUBROUTINE ****					
28A1	BD	27A6	JSR	ADDEM	* SIGNED BCD ADDITION ROUTINE
28AA	BD	27A9	JSR	BCDMULT	* SIGNED BCD MULT. ROUTINE
28EB	BD	27A6	JSR	ADDEM	* SIGNED BCD ADDITION ROUTINE
**** START OF BISUB SUBROUTINE ****					
2920	7E	27D8	JMP	DADD	* TWO BYTE BINARY ADD
**** START OF COMPARE SUBROUTINE ****					
2930	BD	27A6	JSR	ADDEM	* SIGNED BCD ADDITION ROUTINE
**** START OF GENERATE SUBROUTINE ****					
294B	BD	27AC	JSR	RANDOM	* RANDOM NUMBER GENERATOR
2950	BD	279D	JSR	COMPARE	* COMPARE (BCD) VALUE & X
2959	BD	279D	JSR	COMPARE	* COMPARE (BCD) VALUE & X

2965	BD 27AD	JSR	RANDOM	* RANDOM NUMBER GENERATOR
296A	BD 279D	JSR	COMPARE	* COMPARE (BCD) VALUE & X
2973	BD 279D	JSR	COMPARE	* COMPARE (BCD) VALUE & X
298C	BD 2808	JSR	OPGEN	* GENERATE ONE OPERAND
2999	BD 2808	JSR	OPGEN	* GENERATE ONE OPERAND
29AA	BD 27FF	JSR	HI-LO	* SET C IF VALUE BETWEEN LIMITS
29B7	BD 27FF	JSR	HI-LO	* SET C IF VALUE BETWEEN LIMITS
**** START OF REPORT SUBROUTINE ****				
2A43	BD 27C6	JSR	BLANK	* BLANK ENTIRE DISPLAY
2A54	BD 27A6	JSR	ADDEM	* SIGNED BCD ADDITION ROUTINE
2A59	BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2A63	BD 27CC	JSR	UNPACK	* SEPERATE NIBBLES INTO BYTES
2A69	BD 27CF	JSR	SAYNUM	* PRONOUNCE PACKED NUM AT (X)
2A6E	BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2A78	BD 27CC	JSR	UNPACK	* SEPERATE NIBBLES INTO BYTES
2A82	BD 27CF	JSR	SAYNUM	* PRONOUNCE PACKED NUM AT (X)
2A87	BD 27F3	JSR	LDPAUS	* LOAD PAUSE INTO SPEECH BUF.
2A8A	BD 27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
2A8D	BD 27C6	JSR	BLANK	* BLANK ENTIRE DISPLAY
2A97	BD 27CC	JSR	UNPACK	* SEPERATE NIBBLES INTO BYTES
2A9D	BD 27CF	JSR	SAYNUM	* PRONOUNCE PACKED NUM AT (X)
2AA2	BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2AAC	BD 27CC	JSR	UNPACK	* SEPERATE NIBBLES INTO BYTES
2AB2	BD 27CF	JSR	SAYNUM	* PRONOUNCE PACKED NUM AT (X)
2AB7	BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2ABA	BD 27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
**** START OF TEACH SUBROUTINE ****				
2AC0	BD 27DB	JSR	PACK	* PACK MULTIDIGIT INFO
2ACA	BD 27BD	JSR	BISUB	* UNSIGNED BINARY SUBTRACTION
2AD9	BD 27BD	JSR	BISUB	* UNSIGNED BINARY SUBTRACTION
2AE1	BD 27B7	JSR	BCDINC	* INCREMENT (BCD) AT X & X+1
2AF3	BD 27B7	JSR	BCDINC	* INCREMENT (BCD) AT X & X+1
2B1F	BD 27C0	JSR	SAYDISP	* PRONOUNCE PROBLEM

2B25	BD	27C9	JSR	DISPLAY	* LOAD PROB. INTO DISPLAY
2B28	BD	27C3	JSR	BLANKIT	* BLANK MISSING NO. IN DISP.
2B3B	BD	27E7	JSR	GETDIG	* GO GET DIGITS FROM KEYBOARD
2B59	BD	27BA	JSR	ERROR	* APPLY NEG. FEEDBACK
2B6B	BD	27B7	JSR	BCDINC	* INCREMENT (BCD) AT X & X+1
2B73	BD	27F3	JSR	LDPAUS	* LOAD PAUSE INTO SPEECH BUF.
2B76	BD	27C0	JSR	SAYDISP	* PRONOUNCE PROBLEM
2B79	BD	27C9	JSR	DISPLAY	* LOAD PROB. INTO DISPLAY
2B7C	BD	27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
2B82	BD	27F9	JSR	SCAN	* INPUT:KEYS OUTPUT:DISP. & TALK
2B8E	BD	27B7	JSR	BCDINC	* INCREMENT (BCD) AT X & X+1
2B9A	BD	2805	JSR	RIGHT	* APPLY POSITIVE FEEDBACK
2B9F	BD	27B1	JSR	GENERATE	* GENERATE PROBLEM
2BA2	BD	27A3	JSR	GETANS	* FIND CORRECT ANSWER
2BD7	BD	27BD	JSR	BISUB	* UNSIGNED BINARY SUBTRACTION
**** START OF ERROR SUBROUTINE ****					
2C00	BD	27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
2C1C	BD	27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2C21	BD	27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2C25	BD	27C6	JSR	BLANK	* BLANK ENTIRE DISPLAY
2C2B	BD	27F9	JSR	SCAN	* INPUT:KEYS OUTPUT:DISP. & TALK
2C2E	BD	27C9	JSR	DISPLAY	* LOAD PROB. INTO DISPLAY
2C31	BD	27C3	JSR	BLANKIT	* BLANK MISSING NO. IN DISP.
2C37	BD	27F9	JSR	SCAN	* INPUT:KEYS OUTPUT:DISP. & TALK
**** START OF ADDEM SUBROUTINE ****					
2C73	BD	27B4	JSR	BCDADD	* ADD A:B TO LOC @ X
2C94	BD	27B4	JSR	BCDADD	* ADD A:B TO LOC @ X
2CAA	BD	27B7	JSR	BCDINC	* INCREMENT (BCD) AT X & X+1
**** START OF DADD SUBROUTINE ****					
**** START OF TBLOOK SUBROUTINE ****					
2CF9	7E	2000	JMP	\$2000	
2D0B	BD	27B7	JSR	BCDINC	* INCREMENT (BCD) AT X & X+1
**** START OF ADDTBL ****					

```

**** START OF SUBTEL ****
**** START OF M-DTBL ****
**** START OF BLANK SUBROUTINE ****
**** START OF PACK SUBROUTINE ****
**** START OF RIGHT SUBROUTINE ****
2F86 BD 2786      JSR      SPKWD      * LOAD WORD INTO SPKBUF
2F8B BD 2786      JSR      SPKWD      * LOAD WORD INTO SPKBUF
2F90 BD 2786      JSR      SPKWD      * LOAD WORD INTO SPKBUF
2F93 BD 27EA      JSR      WAIT       * WAIT UNTIL SPKBUF EMPTY
**** RESTART AND INTERRUPT VECTORS ****
*****
****          END OF CONTROL PROGRAMS          ****
*****
*

```


TABLE III
PROGRAM LISTING

```

////////////////////////////////////
///      THIS LISTING CONTAINS    ///
///      PIA ADDRESSES FOR       ///
///      D1 COMPUTER BOARD       ///
////////////////////////////////////

```

```

*****
****      6800 CONTROL PROGRAM FOR TEACHING MACHINE      ****
****      BY MICHAEL J. LINNIG      MAY 1979      ****
*****

```

**** START OF RESTART PROGRAM ****

```

2000 CE 0053      LDX      #$0053      * LOAD DELAY VALUE CONSTANT
2003 DF 46        STX      RATE
2005 7F 0061      CLR      SAY
2008 01          NOP
2009 8E 00FF      LDS      #$00FF      * INITIALIZE STACK POINTER
200C 4F          CLR      A
200D CE 8004      LDX      #$0004
2010 A7 05        STA      5,X      * SPECIFY DATA DIR REG IN PIA
2012 A7 07        STA      7,X      * SPECIFY DATA DIR REG IN PIA
2014 86 FF        LDA      #$FF      * LOAD DIR REGS
2016 A7 04        STA      4,X
2018 86 FC        LDA      #$FC
201A A7 06        STA      6,X

201C 86 34        LDA      #$34
201E A7 05        STA      5,X      * INIT CONT-A
2020 86 3D        LDA      #$3D
2022 A7 07        STA      7,X      * INIT CONT-B (START=1)
2024 7E 2030      JMP      $2030

```

**** START OF INTERRUPT PROGRAM ****

```

2027 86 3D        LDA      #$3D
2029 B7 800B      STA      CONT-B      * START=1
202C B6 800A      LDA      PORT-B      * RESET INT BIT IN CONTB
202F 3B          RTI

```

**** END OF INTERRUPT PROGRAM ****

**** START OF RESTART (2) PROGRAM ****

2030 CE 001D	LDX	#\$001D	* INITIALIZE NEXT & LAST
2033 FF 0016	STX	NEXT	
2036 FF 0018	STX	LAST	
2039 CE 0006	LDX	#\$0006	* -----
203C 86 FF	LDA A	#\$FF	* CLEAR DISBUF
203E A7 00	STA A	0,X	
2040 08	INX		
2041 8C 0016	CPX	#\$0016	* END OF DISBUF?
2044 26 F8	BNE	\$203E	

**** END OF RESTART (2) ****

**** START OF MAIN PROGRAM ****

2046 BD 27D2	JSR	PROGRAM	* TEACHER DEFINES PROB. SETS
2049 BD 27ED	JSR	DRILL	* KEYBOARD TRAINING DRILL
204C DE 4A	LDX	SEED1	* IF SEEDS ARE EQUAL
204E 9C 62	CPX	SEED2	* THEN CHANGE SEEDA
2050 26 06	BNE	\$2058	
2052 96 4B	LDA A	SEED1+1	
2054 88 0F	EOR A	#\$0F	
2056 97 4B	STA A	SEED1+1	
2058 96 48	LDA A	MODE	
205A 81 0C	CMP A	#\$0C	
205C 26 03	BNE	\$2061	* IF PROB SET MODE THEN
205E BD 27A0	JSR	TBLOOK	* LOOK UP PROBLEM SET INFO
2061 01	NOP		
2062 01	NOP		
2063 01	NOP		
2064 BD 279A	JSR	TEACH	* TEACH MATH PROBLEMS
2067 7F 0061	CLR	SAY	* DISABLE REPEAT BUTTON
206A BD 27FC	JSR	REPORT	* GIVE TOTAL RIGHT & TIME
206D BD 27C6	JSR	BLANK	* BLANK ENTIRE DISPLAY

2070 86 3C	LDA A	##3C	* SAY "STOP"
2072 BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2075 CE FFFF	LDX	##FFFF	* CALL SCAN UNTIL KEY RELEASED
2078 BD 27F9	JSR	SCAN	* INPUT:KEYS OUTPUT:DISP. & TALK
207B 96 00	LDA A	KEY	
207D 81 17	CMP A	##17	* KEY=REPEAT THEN REPEAT PROBS
207F 26 E9	BNE	\$206A	* ELSE REPORT
2081 7E 204C	JMP	\$204C	

**** END OF MAIN ****

**** START OF RANDOM SUBROUTINE ****

209F A6 00	LDA A	0,X	* CHECK FOR ZERO
20A1 84 07	AND A	##07	* IN B0-B10
20A3 AA 01	ORA A	1,X	
20A5 26 02	BNE	\$20A9	
20A7 63 01	COM	1,X	* REMOVE ZERO
20A9 A6 00	LDA A	0,X	
20AB 44	LSR A		
20AC 44	LSR A		
20AD A8 00	EOR A	0,X	
20AF 44	LSR A		* B0*=B0 EOR B10
20B0 69 01	ROL	1,X	
20B2 69 00	ROL	0,X	
20B4 A6 00	LDA A	0,X	* DESTROY PREDICTABILITY
20B6 88 A5	EOR A	##A5	
20B8 84 03	AND A	##03	
20BA 36	PSH A		
20BB A6 01	LDA A	1,X	
20BD 88 A5	EOR A	##A5	
20BF CE 0000	LDX	##0000	* CLR RUNNING TOTAL
20C2 DF 75	STX	VALUE	
20C4 FE 27AF	LDX	\$27AF	* STARTING ADDR OF BCD TABLE
20C7 DF 04	STX	XSAV	
20C9 8D 10	BSR	\$20DB	
20CB 32	PUL A		
20CC 8D 0D	BSR	\$20DB	
20CE CE 8000	LDX	##8000	* VALUE=MINUS ZERO?
20D1 9C 75	CPX	VALUE	
20D3 26 05	BNE	\$20DA	
20D5 CE 8421	LDX	##8421	* VALUE=-421
20D8 DF 75	STX	VALUE	

```

20DA 39          RTS
20DB DE 04      LDX   XSAV          * CONVERT SUBROUTINE
20DD 44          LSR A
20DE 24 0C      BCC   $20EC          * IF BIT0=1 THEN ADD
20E0 36          PSH A          * MEMORY ADDRESSED BY X
20E1 A6 00      LDA A   0,X          * TO VALUE
20E3 E6 01      LDA B   1,X
20E5 CE 0075    LDX   #$0075
20E8 BD 27B4    JSR   BCDADD          * ADD A:B TO LOC @ X
20EB 32          PUL A
20EC DE 04      LDX   XSAV          * RECOVER ADDRESS
20EE 08          INX
20EF 08          INX
20F0 DF 04      STX   XSAV
20F2 4D          TST A
20F3 26 E6      BNE   $20DB
20F5 EE 00      LDX   0,X          * ADJUST ADDR
20F7 8C 0256    CPX   #$0256          * LAST TBL ENTRY?
20FA 26 F0      BNE   $20EC
20FC 39          RTS

```

**** START OF BCDTBL LOOK UP TABLE ****

```

20FD 00 01
      00 02
      00 04
      00 08
      00 16
      00 32
      00 64
      01 28
      02 56
      80 00
2111 02 56

```

**** END OF BCDTBL ****

**** START OF OPGEN SUBROUTINE ****

```

211D 8D 0C      BSR   $212B
211F DE 75      LDX   VALUE
2121 8C 8000    CPX   #$8000          * TEST FOR MINUS ZERO

```

2124 26 04	BNE	\$212A	
2126 8D 07	BSR	\$212F	
2128 20 F5	BRA	\$211F	
212A 39	RTS		
212B 97 03	STA A	SUM	* OPGEN1 SUBROUTINE
212D DF 81	STX	ADDRESS	
212F DE 81	LDX	ADDRESS	* AGAIN STARTS BELOW
2131 BD 27AC	JSR	RANDOM	* RANDOM NUMBER GENERATOR
2134 BD 27FF	JSR	HI-LO	* SET C IF VALUE BETWEEN LIMITS
2137 04 99			* <499
2139 84 99			* >-499
213B 24 F2	BCC	\$212F	* GOTO AGAIN IF OUTSIDE LIMITS
213D 96 03	LDA A	SUM	
213F 81 0B	CMP A	##0B	
2141 2C 49	BGE	\$218C	* BR IF 3 DIG NO. ASKED FOR
2143 D6 75	LDA B	VALUE	
2145 C4 F0	AND B	##F0	
2147 D7 75	STA B	VALUE	* MASK OFF HUNDREDS
2149 81 0B	CMP A	##0B	
214B 2C 54	BGE	\$21A1	* BR IF 2 DIG NO. ASKED FOR
214D D6 76	LDA B	VALUE+1	
214F C4 0F	AND B	##0F	* MASK OFF TENS
2151 D7 76	STA B	VALUE+1	
2153 81 06	CMP A	##06	
2155 2C 5F	BGE	\$21B6	* BR IF MULT OF 10 REQ'D
2157 81 05	CMP A	##05	
2159 26 01	BNE	\$215C	* BR IF +-9 NOT REQ'D
215B 39	RTS		
215C 81 04	CMP A	##04	
215E 26 02	BNE	\$2162	
2160 20 24	BRA	\$2186	* 0 TO 9
2162 BD 27FF	JSR	HI-LO	* SET C IF VALUE BETWEEN LIMITS
2165 00 04			* < +4
2167 80 04			* > -4
2169 24 0C	BCC	\$2177	
216B 7D 0003	TST	SUM	
216E 27 16	BEQ	\$2186	* BR IF SUM=0
2170 96 03	LDA A	SUM	
2172 81 01	CMP A	##01	
2174 26 B9	BNE	\$212F	
2176 39	RTS		* HERE IF SUM=1
2177 96 03	LDA A	SUM	
2179 81 02	CMP A	##02	
217B 26 02	BNE	\$217F	
217D 20 07	BRA	\$2186	* HERE IF SUM=2
217F 81 03	CMP A	##03	
2181 26 01	BNE	\$2184	
2183 39	RTS		* HERE IF SUM=3
2184 20 A9	BRA	\$212F	* STEPPING STONES
2186 20 3B	BRA	\$21C3	* STEPPING STONES

```

2188 01      NOP
2189 01      NOP
218A 01      NOP
218B 01      NOP

218C 81 0D      CMP A  #$0D      * SUM=0D?
218E 26 01      BNE  $2191
2190 39          RTS
2191 BD 27FF      JSR  HI-LO      * SET C IF VALUE BETWEEN LIMITS
2194 00 99          * < +99
2196 80 99          * > -99
2198 25 E8      BCS  $2184
219A 96 03      LDA A  SUM
219C 81 0C      CMP A  #$0C
219E 26 23      BNE  $21C3
21A0 39          RTS

21A1 81 0A      CMP A  #$0A
21A3 26 01      BNE  $21A6
21A5 39          RTS
21A6 BD 27FF      JSR  HI-LO      * SET C IF VALUE BETWEEN LIMITS
21A9 00 09          * < +9
21AB 80 09          * > -9
21AD 25 D5      BCS  $2184
21AF 96 03      LDA A  SUM
21B1 81 08      CMP A  #$08
21B3 27 0E      BEQ  $21C3
21B5 39          RTS

21B6 D6 76      LDA B  VALUE+1      * MOVE ONES TO TENS PLACE
21B8 58          ASL B
21B9 5C          ASL B
21BA 58          ASL B
21BB 58          ASL B
21BC D7 76      STA B  VALUE+1
21BE 81 04      CMP A  #$06
21C0 27 01      BEQ  $21C3
21C2 39          RTS

21C3 96 75      LDA A  VALUE      * ABSOLUTE VALUE SUBROUTINE
21C5 84 0F      AND A  #$0F
21C7 97 75      STA A  VALUE
21C9 39          RTS

```

**** START OF HI-LO SUBROUTINE ****

```

21CA BD 2802      JSR  LOADX      * LOAD X FROM INLINE DATA
21CD BD 279D      JSR  COMPARE    * COMPARE (BCD) VALUE & X
21D0 2B 07      BMI  $21D9
21D2 27 05      BEQ  $21D9

```

```

21D4 BD 2802    JSR    LOADX      * LOAD X FROM INLINE DATA
21D7 0C         CLC
21D8 39         RTS              * HERE IF HILIM TEST FAILS

21D9 BD 2802    JSR    LOADX      * LOAD X FROM INLINE DATA
21DC BD 279D    JSR    COMPARE    * COMPARE (BCD) VALUE & X
21DF 0C         CLC
21E0 2A 01     BPL     $21E3
21E2 39         RTS              * HERE IF LOLIM FAILS TEST

21E3 0D         SEC
21E4 39         RTS              * HERE IF BETWEEN LIMITS

```

**** START OF DOWN UTILITY PROGRAM ****

```

220F FE 2202    LDX     $2202
2212 08         INX
2213 08         INX
2214 FF 2202    STX     $2202
2217 FE 2200    LDX     $2200
221A A6 00     LDA A   0,X
221C 08         INX
221D BC 2202    CFX     $2202
2220 27 0E     BEQ     $2230
2222 FF 2200    STX     $2200
2225 FE 2204    LDX     $2204
2228 A7 00     STA A   0,X
222A 08         INX
222B FF 2204    STX     $2204
222E 20 E7     BRA     $2217

```

**** START OF DISPLAY SUBROUTINE ****

```

2240 86 88     LDA A   #$88
2242 97 13     STA A   $0013      * TURN ON EQUALS
2244 96 5B     LDA A   NUM1
2246 D6 5C     LDA B   NUM1+1     * LOAD FIRST DISPLAY
2248 CE 0006    LDX     #$0006
224B BD 27CC    JSR     UNPACK    * SEPERATE NIBBLES INTO BYTES
224E 96 5D     LDA A   NUM2
2250 D6 5E     LDA B   NUM2+1     * LOAD 2ND DISPLAY
2252 CE 000A    LDX     #$000A
2255 BD 27CC    JSR     UNPACK    * SEPERATE NIBBLES INTO BYTES
2258 96 5F     LDA A   NUM3
225A D6 60     LDA B   NUM3+1     * LOAD 3RD DISPLAY
225C CE 000E    LDX     #$000E
225F BD 27CC    JSR     UNPACK    * SEPERATE NIBBLES INTO BYTES

2262 86 13     LDA A   #$13

```

```

2264 C6 EF      LDA B  #$EF
2266 91 50      CMP A  OPSIGN      * LOAD OPERATION SIGN
2268 27 04      BEQ   $226E
226A 4A        DEC A
226B 58        ASL B
226C 20 F8      BRA   $2266
226E D7 12      STA B  $0012
2270 01        NOP
2271 01        NOP
2272 01        NOP
2273 CE 0007    LDX   #$0007
2276 8D 0B      BSR   $2283
2278 CE 000B    LDX   #$000B
227B 8D 06      BSR   $2283
227D CE 000F    LDX   #$000F
2280 8D 01      BSR   $2283
2282 39        RTS

2283 6D 00      TST   0,X          * LEADING ZERO SUPPRESS
2285 26 08      BNE   $228F
2287 63 00      COM   0,X
2289 6D 01      TST   1,X
228B 26 02      BNE   $228F
228D 63 01      COM   1,X
228F 39        RTS

```

**** START OF UP UTILITY PROGRAM ****

```

229F FE 2290    LDX   $2290
22A2 09        DEX
22A3 09        DEX
22A4 FF 2290    STX   $2290
22A7 FE 2292    LDX   $2292
22AA A6 00      LDA A  0,X
22AC 09        DEX
22AD BC 2290    CPX   $2290
22B0 27 0E      BEQ   $22C0
22B2 FF 2292    STX   $2292
22B5 FE 2294    LDX   $2294
22B8 A7 00      STA A  0,X
22BA 09        DEX
22BB FF 2294    STX   $2294
22BE 20 E7      BRA   $22A7

```

**** START OF BCDADD SUBROUTINE ****

```

22C7 36        PSH A
22C8 17        TBA

```



```

22C9 AB 01      ADD A 1,X          * ADD LOW BYTES
22CB 19         DAA
22CC A7 01      STA A 1,X
22CE 16         TAB
22CF 32         PUL A
22D0 A9 00      ADC A 0,X          * ADD HIGH BYTES
22D2 19         DAA
22D3 A7 00      STA A 0,X
22D5 39         RTS

```

**** START OF BCDINC SUBROUTINE ****

```

22D6 4F         CLR A
22D7 C6 01      LDA B #$01
22D9 7E 27B4    JMP BCDADD        * ADD A:B TO LOC @ X

```

**** START OF LOADX SUBROUTINE ****

```

22DC 36         PSH A
22DD 37         PSH B              * SAVE A AND B
22DE 30         TSX

22DF A6 04      LDA A 4,X
22E1 E6 05      LDA B 5,X
22E3 C3 02      ADD B #02          * ADD 2 TO RTN ADDR OF 2ND
22E5 89 00      ADC A #$00        * CALL ROUTINE ON STACK
22E7 A7 04      STA A 4,X
22E9 E7 05      STA B 5,X

22EB EE 04      LDX 4,X           * X=RTN ADDR OF 2ND CALL
22ED 09         DEX
22EE 09         DEX
22EF EE 00      LDX 0,X          * GET INLINE DATA

22F1 33         PUL B
22F2 32         PUL A            RESTORE A AND B
22F3 39         RTS

```

**** START OF PROGRAM SUBROUTINE ****

```

22F4 20 0C      BRA $2302
22F6 86 31      LDA A #$31        * PATCH TO LOAD ACTUAL
22F8 97 00      STA A KEY         * NO. OF SCANS/SEC

```

22FA 39	RTS	
22FB 97 49	STA A	OPTION
22FD DE 1A	LDX	SCNTIM
22FF DF 62	STX	SEED2
2301 39	RTS	
2302 CE 0001	LDX	##0001
2305 DF 46	STX	RATE
2307 86 10	LDA A	##10
2309 97 14	STA A	\$0014
230B BD 27E1	JSR	2BEEP
230E CE FFFE	LDX	##FFFE
2311 BD 27F9	JSR	SCAN
2314 96 00	LDA A	KEY
2316 BD 27F0	JSR	SPKEY
2319 96 00	LDA A	KEY
231B 81 0B	CMP A	##0B
231D 27 04	BEQ	\$2323
231F 81 0C	CMP A	##0C
2321 26 E4	BNE	\$2307
2323 97 48	STA A	MODE
2325 DE 1A	LDX	SCNTIM
2327 DF 4A	STX	SEED1
2329 86 20	LDA A	##20
232B 97 14	STA A	\$0014
232D BD 27E1	JSR	2BEEP
2330 CE FFFE	LDX	##FFFE
2333 BD 27F9	JSR	SCAN
2336 96 00	LDA A	KEY
2338 BD 27F0	JSR	SPKEY
233B 96 00	LDA A	KEY
233D 81 0D	CMP A	##0D
233F 2D E8	BLT	\$2329
2341 81 0F	CMP A	##0F
2343 2E E4	BGT	\$2329
2345 BD B4	BSR	\$22FB
2347 CE 0053	LDX	##0053
234A DF 46	STX	RATE
234C 96 49	LDA A	OPTION
234E 81 0F	CMP A	##0F
2350 27 3B	BEQ	\$238D
2352 86 30	LDA A	##30
2354 97 14	STA A	\$0014
2356 BD 27E1	JSR	2BEEP
2359 CE FFFF	LDX	##FFFF
235C BD 27E7	JSR	GETDIG
235F CE 004C	LDX	##004C
2362 BD 27DE	JSR	MINTOBI
2365 96 49	LDA A	OPTION
2367 81 0E	CMP A	##0E
2369 26 22	BNE	\$238D

* PATCH TO LOAD OPTION
* AND SEED2
* TURN SCAN RATE TO MAX
* TURN MODE PROMPT ON
* SAY "GO PLEASE"
* INPUT:KEYS OUTPUT:DISP. & TALK
* ECHO KEY NAME
* 0B=BOUNDED MODE
* 0C=LEVEL MODE
* LOAD RANDOM NO. SEED
* PROMPT OPTION
* SAY "GO PLEASE"
* INPUT:KEYS OUTPUT:DISP. & TALK
* ECHO KEY NAME
* 0D=TIMED OPTION KEY
* 0F=POWER OPTION KEY
* TO LOAD SEED2 & OPTION PATCH
* RESTORE NORMAL SCAN RATE
* OPTION = POWER?
* PROMPT TIME LIMIT
* SAY "GO PLEASE"
* GO GET DIGITS FROM KEYBOARD
* CONVERT MMM:SS TO BIN. SECS
* OPTION=SPEED?

236B FE 004C	LDX	TIMLIM	
236E DF 04	STX	XSAV	
2370 8D 84	BSR	\$22F6	
2372 7D 0000	TST	KEY	* ADD TIMLIM TO SELF 50 TIMES
2375 27 16	BEQ	\$238D	* TO GET NUMBER OF SCANS/PROB
2377 CE 004C	LDX	\$\$004C	
237A 96 04	LDA A	XSAV	
237C D6 05	LDA B	XSAV+1	
237E BD 27D8	JSR	DADD	* TWO BYTE BINARY ADD
2381 25 05	BCS	\$2388	
2383 7A 0000	DEC	KEY	
2386 20 EA	BRA	\$2372	
2388 CE FFFF	LDX	\$\$\$\$\$	* SET TIME LIMIT TO INFINITY
238B DF 4C	STX	TIMLIM	
238D 96 49	LDA A	OPTION	
238F 81 0D	CMP A	\$\$0D	* TIMED?
2391 27 13	BEQ	\$23A6	
2393 86 40	LDA A	\$\$40	
2395 97 14	STA A	\$0014	* PROMPT NO. OF PROBLEMS
2397 BD 27E1	JSR	2BEEP	* SAY 'GO PLEASE'
239A CE FFFF	LDX	\$\$\$\$\$	
239D BD 27E7	JSR	GETDIG	* GO GET DIGITS FROM KEYBOARD
23A0 CE 004E	LDX	\$\$004E	
23A3 BD 27DB	JSR	PACK	* PACK MULTIDIGIT INFO
23A6 86 50	LDA A	\$\$50	
23A8 97 14	STA A	\$0014	* PROMPT OPERATION SIGN
23AA BD 27E1	JSR	2BEEP	* SAY 'GO PLEASE'
23AD CE FFFF	LDX	\$\$\$\$\$	
23B0 BD 27F9	JSR	SCAN	* INPUT:KEYS OUTPUT:DISP. & TALK
23B3 96 00	LDA A	KEY	
23B5 BD 27F0	JSR	SPKEY	* ECHO KEY NAME
23B8 96 00	LDA A	KEY	
23BA 81 10	CMP A	\$\$10	* CHECK FOR LEGAL KEY
23BC 2D E8	BLT	\$23A6	
23BE 81 13	CMP A	\$\$13	
23C0 2E E4	BGT	\$23A6	
23C2 97 50	STA A	OPSIGN	
23C4 86 60	LDA A	\$\$60	
23C6 97 14	STA A	\$0014	* PROMPT MISSING NO.
23C8 BD 27E1	JSR	2BEEP	* SAY 'GO PLEASE'
23CB CE FFFF	LDX	\$\$\$\$\$	
23CE BD 27E7	JSR	GETDIG	* GO GET DIGITS FROM KEYBOARD
23D1 CE 0051	LDX	\$\$0051	
23D4 BD 27DB	JSR	PACK	* PACK MULTIDIGIT INFO
23D7 96 48	LDA A	MODE	
23D9 81 0B	CMP A	\$\$0B	
23DB 27 14	BEQ	\$23F1	* MODE = BOUNDED?
23DD 86 70	LDA A	\$\$70	
23DF 97 14	STA A	\$0014	* PROMPT LEVEL OF DIFFICULTY

23E1 BD 27E1	JSR	2BEEP	* SAY "GO PLEASE"
23E4 CE FFFF	LDX	\$\$FFFF	
23E7 BD 27E7	JSR	GETDIG	* GO GET DIGITS FROM KEYBOARD
23EA CE 0053	LDX	\$\$0053	
23ED BD 27DB	JSR	PACK	* PACK MULTIDIGIT INFO
23F0 39	RTS		
23F1 86 80	LDA A	\$\$80	* PROMPT FOR HILIM1
23F3 BD 27D5	JSR	GETEM	* PROMPT & SCAN FOR RESPONSE
23F6 CE 0053	LDX	\$\$0053	
23F9 BD 27DB	JSR	PACK	* PACK MULTIDIGIT INFO
23FC 86 90	LDA A	\$\$90	* PROMPT FOR LOLIM1
23FE BD 27D5	JSR	GETEM	* PROMPT & SCAN FOR RESPONSE
2401 CE 0055	LDX	\$\$0055	
2404 BD 27DB	JSR	PACK	* PACK MULTIDIGIT INFO
2407 86 80	LDA A	\$\$80	* PROMPT FOR HILIM2
2409 BD 27D5	JSR	GETEM	* PROMPT & SCAN FOR RESPONSE
240C CE 0057	LDX	\$\$0057	
240F BD 27DB	JSR	PACK	* PACK MULTIDIGIT INFO
2412 86 90	LDA A	\$\$90	* PROMPT FOR LOLIM2
2414 BD 27D5	JSR	GETEM	* PROMPT & SCAN FOR RESPONSE
2417 CE 0059	LDX	\$\$0059	
241A BD 27DB	JSR	PACK	* PACK MULTIDIGIT INFO
241D 39	RTS		

**** START OF 2BEEP SUBROUTINE ****

2455 BD 27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
2458 86 19	LDA A	\$\$19	* INSERT 1/2 SEC PAUSE
245A BD 27F3	JSR	LDPAUS	* LOAD PAUSE INTO SPEECH BUF.
245D 86 3B	LDA A	\$\$3B	* INSERT "GO"
245F BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2462 86 2F	LDA A	\$\$2F	* INSERT "PLEASE"
2464 BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2467 39	RTS		

**** START OF MINTOBI SUBROUTINE ****

2469 20 05	BRA	\$2470	
246B BD 27D8	JSR	DADD	* TWO BYTE BINARY ADD
246E 20 28	BRA	\$2498	
2470 6F 00	CLR	0,X	
2472 6F 01	CLR	1,X	* CLEAR RUNNING TOTAL
2474 96 3E	LDA A	DIG1	
2476 A7 01	STA A	1,X	* SECONDS

2478 7D 003F	TST	DIG2	
247B 27 0B	BEQ	\$2488	
247D 4F	CLR A		
247E C6 0A	LDA B	#\$0A	* MULT DIG2 BY 10 & ADD TO VAL.
2480 BD 27D8	JSR	DADD	* TWO BYTE BINARY ADD
2483 7A 003F	DEC	DIG2	
2486 20 F0	BRA	\$2478	
2488 7D 0040	TST	DIG3	
248B 27 0B	BEQ	\$2498	
248D 4F	CLR A		
248E C6 3C	LDA B	#\$3C	* DIG3 X \$3C (X60)
2490 BD 27D8	JSR	DADD	* TWO BYTE BINARY ADD
2493 7A 0040	DEC	DIG3	
2496 20 F0	BRA	\$2488	
2498 7D 0041	TST	DIG4	
249B 27 09	BEQ	\$24A6	
249D 86 02	LDA A	#\$02	
249F C6 58	LDA B	#\$58	* DIG4 X \$0258 (X600)
24A1 7A 0041	DEC	DIG4	
24A4 20 C5	BRA	\$246B	
24A6 39	RTS		

**** START OF SAYNUM SUBROUTINE ****

24A7 A6 00	LDA A	0,X	
24A9 E6 01	LDA B	1,X	* MOVE NO. TO A:B
24AB 4D	TST A		
24AC 20 42	BRA	\$24F0	
24AE 36	PSH A		* HERE IF NO IS MINUS
24AF 86 1F	LDA A	#\$1F	* SAY 'MINUS'
24B1 BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
24B4 32	PUL A		
24B5 84 0F	AND A	#\$0F	
24B7 27 0B	BEQ	\$24C1	* BR IF NO HUNDREDS
24B9 BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
24BC 86 1C	LDA A	#\$1C	* 'HUNDRED'
24BE BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
24C1 86 0A	LDA A	#\$0A	* 1/5 SEC DELAY
24C3 BD 27F3	JSR	LDPAUS	* LOAD PAUSE INTO SPEECH BUF.
24C6 37	PSH B		
24C7 54	LSR B		
24C8 C1 10	CMP B	#\$10	* BRANCH IF TEENS
24CA 33	PUL B		
24CB 2D 0C	BLT	\$24D9	
24CD 17	TBA		

```

24CE 44      LSR A
24CF 44      LSR A
24D0 44      LSR A
24D1 44      LSR A
24D2 8B 12    ADD A  #$12      * ADJUST TO SAY TENS DIGIT
24D4 BD 27F6  JSR  SPKWD      * LOAD WORD INTO SPEECH BUF.
24D7 20 0D    BRA  $24E6

24D9 C5 10    BIT B  #$10      * HERE IF TEENS
24DB 27 09    BEQ  $24E6
24DD 17      TBA
24DE 84 0F    AND A  #$0F
24E0 8B 0A    ADD A  #$0A      * SAY (ONES DIGIT + 10)
24E2 BD 27F6  JSR  SPKWD      * LOAD WORD INTO SPEECH BUF.
24E5 39      RTS

24E6 C4 0F    AND B  #$0F
24E8 26 01    BNE  $24EB
24EA 39      RTS              * RTS IF ONES DIGIT = 0
24EB 17      TBA
24EC BD 27F6  JSR  SPKWD      * LOAD WORD INTO SPEECH BUF.
24EF 39      RTS

24F0 26 09    BNE  $24FB
24F2 5D      TST B
24F3 26 06    BNE  $24FB

24F5 86 00    LDA A  #$00      * HERE IF NUM = 0
24F7 BD 27F6  JSR  SPKWD      * LOAD WORD INTO SPEECH BUF.
24FA 39      RTS

24FB 4D      TST A
24FC 2A B7    BPL  $24B5
24FE 20 AE    BRA  $24AE

```

**** START OF SCAN SUBROUTINE ****

```

2500 FF 001A  STX  SCNTIM      * SAVE NUM OF SCANS TO DO
2503 7F 0000  CLR  KEY
2506 7F 0001  CLR  BF          * INITIALIZE

2509 7F 0002  CLR  DADDR
250C 7F 0003  CLR  SUM
250F CE 0006  LDX  #$0006      * $0006 IS START OF DISBUF
2512 FF 0004  STX  XSAV

2515 FE 0004  LDX  XSAV      * OUTPUT DATA AND DEV ADDR
2518 A6 00    LDA A  0,X
251A 84 F0    AND A  #$F0
251C BA 0002  ORA A  DADDR
251F B7 8008  STA A  PORT-A

```

```

2522 8D 2D      BSR      $2551      * STROBE DECODER & DELAY
2524 01        NOP
2525 01        NOP
2526 01        NOP
2527 84 03      AND A    #$03      * MASK OFF ALL BUT KEY BITS
2529 36        PSH A
252A 44        LSR A
252B B9 0003    ADC A    SUM      * SUM CONTAINS # OF KEYS DOWN
252E B7 0003    STA A    SUM
2531 32        PUL A

2532 4D        TST A
2533 27 0D      BEQ      $2542      * BR IF NO KEY THIS ADDR
2535 44        LSR A
2536 78 0002    ASL      DADDR
2539 BA 0002    ORA A    DADDR      * GENERATE CODE FOR KEY
253C B7 0000    STA A    KEY
253F 77 0002    ASR      DADDR

2542 7C 0002    INC      DADDR      * NEXT DEV. ADDRESS
2545 7C 0005    INC      XSAV+1     * NEXT BUFFER ADDRESS
2548 B6 0002    LDA A    DADDR
254B 81 10      CMP A    #$10      * DADDR BEYOND RANGE?
254D 26 C6      BNE      $2515
254F 20 16      BRA      $2567

2551 86 34      LDA A    #$34
2553 B7 8009    STA A    CONT-A     * SET CA2 LOW TO STROBE DEC.
2556 FE 0046    LDX      RATE
2559 09        DEX
255A 26 FD      BNE      $2559      * DELAY LOOP TO SET SCAN RATE
255C B6 800A    LDA A    PORT-B     * TO 50 SCANS/SEC
255F 36        PSH A               * BRING IN KEY BITS
2560 86 3C      LDA A    #$3C
2562 B7 8009    STA A    CONT-A     * SET CA2 HIGH
2565 32        PUL A
2566 39        RTS

```

**** START OF CHECK SPEECH ROUTINE ****

```

2567 01        NOP
2568 0E        CLI
2569 86 08      LDA A    #$08      * BRANCH IF START = 0
256B E5 800B    BIT A    CONT-B
256E 27 4A      BEQ      $25BA
2570 FE 0016    LDX      NEXT
2573 BC 0018    CPX      LAST
2576 27 42      BEQ      $25BA
2578 7D 001C    TST      PAUSE
257B 26 2B      BNE      $25A8

257D B6 800A    LDA A    PORT-B

```

2580 84 FC	AND A	#\$FC	* MASK OFF KEY INPUTS
2582 A1 00	CMP A	0,X	
2584 26 0A	BNE	\$2590	* BR IF NEXT WORD NOT AT PORTB
2586 86 35	LDA A	#\$35	
2588 B7 800B	STA A	CONT-B	* START=0 (BEGIN TALKING)
258B 7C 0017	INC	NEXT	* POINT TO NEXT WORD
258E 20 2A	BRA	\$25BA	
2590 86 03	LDA A	#\$03	
2592 FE 0016	LDX	NEXT	* IF 2 LSB'S OF NEXT WORD = 0
2595 A5 00	BIT A	0,X	* THEN WORD IS VALID
2597 27 14	BEQ	\$25AD	
2599 A6 00	LDA A	0,X	* LOAD NEXT "WORD" INTO PAUSE
259B B7 001C	STA A	PAUSE	
259E 7C 0017	INC	NEXT	
25A1 86 FF	LDA A	#\$FF	* FLAG INDICATING PAUSE
25A3 B7 800A	STA A	PORT-B	
25A6 20 12	BRA	\$25BA	
25A8 7A 001C	DEC	PAUSE	
25AB 20 0D	BRA	\$25BA	
25AD 86 01	LDA A	#\$01	* 20MS PAUSE BETWEEN WORDS
25AF B7 001C	STA A	PAUSE	
25B2 FE 0016	LDX	NEXT	
25B5 A6 00	LDA A	0,X	* OUTPUT NEXT WORD TO PORT-B
25B7 B7 800A	STA A	PORT-B	
25BA FE 0016	LDX	NEXT	* CORRECT NEXT IF IT IS
25BD 8C 003D	CPX	#\$003D	* BEYOND SPEECH BUFFER
25C0 26 03	BNE	\$25C5	
25C2 CE 001D	LDX	#\$001D	
25C5 FF 0016	STX	NEXT	
25C8 01	NOP		
25C9 01	NOP		
25CA 01	NOP		

**** START OF CHECK TIME ROUTINE ****

25CB DE 1A	LDX	SCNTIM	
25CD 8C FFFF	CPX	#\$FFFF	* DEC #SCANS UNLESS = \$FFFF
25D0 27 04	BEQ	\$25D6	
25D2 09	DEX		
25D3 26 01	BNE	\$25D6	* RTS WHEN #SCANS = 0
25D5 39	RTS		
25D6 DF 1A	STX	SCNTIM	
25D8 01	NOP		
25D9 01	NOP		
25DA 01	NOP		

**** START OF KEY DEBOUNCE ROUTINE ****

```

* SUM=0 BF=0      ACTION=NONE
* SUM=1 BF=0      ACTION= BF=1
* SUM=1 BF=1      ACTION= BF=2      WAIT FOR RELEASE
* SUM=1 BF=2      ACTION= NONE      WAIT FOR RELEASE
* SUM=0 BF=1      ACTION= BF=0      INPUT BOUNCE
* SUM=0 BF=2      ACTION= RTS        KEY RELEASED !
* SUM>1 BF=X      ACTION= BF=0      TOO MANY KEYS

25DB B6 0003      LDA A  SUM
25DE 81 01        CMP A  #$01
25E0 2E 0A        BGT   $25EC
25E2 27 0D        BEQ   $25F1
25E4 B6 0001      LDA A  BF
25E7 81 02        CMP A  #$02
25E9 26 01        BNE   $25EC
25EB 39           RTS

25EC 7F 0001      CLR    BF
25EF 20 0A        BRA    $25FB

25F1 B6 0001      LDA A  BF
25F4 81 02        CMP A  #$02
25F6 27 03        BEQ   $25FB
25F8 7C 0001      INC    BF
25FB 7E 27E4      JMP    CONTINUE      * MAKE ANOTHER SCAN

```

**** START OF SPKWD AND LDPAUS SUBROUTINES ****

```

2600 48           ASL A                * ENTER HERE FOR SPKWD
2601 48           ASL A                * SHIFTS WORD

2602 DE 18        LDX    LAST          * ENTER HERE FOR LDPAUS
2604 A7 00        STA A  0,X
2606 08           INX
2607 8C 003D      CPX    #$003D        * ADJ LAST IF OUTSIDE
260A 26 03        BNE    $260F        * OF SPEECH BUFFER

260C CE 001D      LDX    #$001D
260F DF 18        STX    LAST
2611 39           RTS

```

**** START OF GETEM SUBROUTINE ****

```

2612 97 14        STA A  $0014        * STORE A IN PROMPT BUF

```

2614	BD	27E1	JSR	2BEEP	* SAY "GO PLEASE"
2617	CE	FFFF	LDX	FFFF	
261A	BD	27E7	JSR	GETDIG	* GO GET DIGITS FROM KEYBOARD
261D	39		RTS		

**** START OF SPKEY SUBROUTINE ****

2620	81	0A	CMP	A	0A	* KEY = MINUS
2622	2E	08	BGT		262C	* KEY HAS NO NAME
2624	26	02	BNE		2628	* KEY NAME=KEY VALUE
2626	86	1F	LDA	A	1F	* "MINUS"
2628	BD	27F6	JSR		SPKWD	* LOAD WORD INTO SPEECH BUF.
262B	39		RTS			
262C	86	3E	LDA	A	3E	* "HI-TONE"
262E	20	F8	BRA		2628	

**** START OF DRILL SUBROUTINE ****

2634	86	00	LDA	A	00	* PROMPT KEYBOARD
2636	97	14	STA	A	0014	
2638	5F		CLR	B		
2639	17		TBA			* SAY NEXT KEY
263A	BD	27F0	JSR		SPKEY	* ECHO KEY NAME
263D	86	2F	LDA	A	2F	* "PLEASE"
263F	BD	27F6	JSR		SPKWD	* LOAD WORD INTO SPEECH BUF.
2642	CE	00FA	LDX		00FA	* SCAN FOR 5 SEC. (250 SCANS)
2645	BD	27F9	JSR		SCAN	* INPUT:KEYS OUTPUT:DISP. & TALK
2648	7D	0001	TST		BF	* BF=0 IMPLIES TIMED OUT
264B	27	EC	BEQ		2639	
264D	20	1B	BRA		266A	
264F	36		PSH	A		
2650	BD	27F0	JSR		SPKEY	* ECHO KEY NAME
2653	BD	27EA	JSR		WAIT	* WAIT TILL SPEECH-BUF EMPTY
2656	32		PUL	A		
2657	11		CBA			* KEY CORRECT?
2658	26	E8	BNE		2642	
265A	86	3E	LDA	A	3E	* "HI-TONE"
265C	BD	27F6	JSR		SPKWD	* LOAD WORD INTO SPEECH BUF.
265F	86	25	LDA	A	25	* 37 SCANS
2661	BD	27F3	JSR		LDPFAUS	* LOAD PAUSE INTO SPEECH BUF.
2664	5C		INC	B		
2665	C1	0B	CMP	B	0B	* LAST KEY?
2667	26	D0	BNE		2639	

```

2669 39          RTS
266A 96 00      LDA A  KEY
266C 81 17      CMP A  #$17
266E 26 DF      BNE    $264F
2670 39          RTS

```

**** START OF WAIT SUBROUTINE ****

```

2680 CE 000A    LDX    #$000A      * 10 SCANS
2683 BD 27F9    JSR    SCAN        * INPUT:KEYS  OUTPUT:DISP. & TALK
2686 DE 16      LDX    NEXT
2688 9C 18      CPX    LAST        * IF SPEECH BUFFER NOT EMPTY
268A 26 F4      BNE    $2680        * CONTINUE SCANNING UNTIL IT IS
268C 39          RTS

```

**** START OF GETDIG SUBROUTINE ****

```

268D DF 44      STX    TIMER        * STORE # OF SCANS
268F CE 003D    LDX    #$003D
2692 6F 00      CLR    0,X
2694 08          INX
2695 8C 0044    CPX    $0044
2698 26 F8      BNE    $2692
269A DE 44      LDX    TIMER        * RETRIEVE #SCANS
269C BD 27F9    JSR    SCAN        * INPUT:KEYS  OUTPUT:DISP. & TALK
269F 7D 003D    TST    SGNDIG
26A2 26 04      BNE    $26A8
26A4 DE 1A      LDX    SCNTIM
26A6 DF 44      STX    TIMER        * STORE # OF SCANS USED
26A8 20 14      BRA    $26BE
26AA 96 00      LDA A  KEY
26AC 20 36      BRA    $26E4        * TO PATCH
26AE 01          NOP
26AF 81 0A      CMP A  #$0A        * EQUAL TO MINUS?
26B1 26 12      BNE    $26C5
26B3 86 80      LDA A  #$80        * SET SIGN BIT IN SGNDIG
26B5 9A 3D      ORA A  SGNDIG
26B7 97 3D      STA A  SGNDIG
26B9 FE 0044    LDX    TIMER
26BC 20 DE      BRA    $269C        * GO GET NEXT KEY
26BE 96 01      LDA A  BF
26C0 81 02      CMP A  #$02        * BF=2 IS VALID KEY ELSE TIMEOUT
26C2 27 E6      BEQ    $26AA
26C4 39          RTS

```

26C5 2F 03	BLE	\$26CA	
26C7 20 22	BRA	\$26EB	* KEY NOT VALID
26C9 01	NOP		
26CA 7C 003D	INC	SGNDIG	
26CD CE 003E	LDX	##003E	* PUSH DOWN DIGITS
26D0 E6 00	LDA B	0,X	* SO LAST ENTRY AT DIG1
26D2 A7 00	STA A	0,X	
26D4 17	TBA		
26D5 08	INX		
26D6 8C 0044	CPX	##0044	
26D9 26 F5	BNE	\$26D0	
26DB 96 3D	LDA A	SGNDIG	
26DD 84 7F	AND A	##7F	
26DF 81 06	CMP A	##06	* IF NO DIGITS > OR = 6 RTS
26E1 2D D6	BLT	\$26B9	
26E3 39	RTS		
26E4 BD 27F0	JSR	SPKEY	* ECHO KEY NAMES
26E7 96 00	LDA A	KEY	* THIS PATCH COMPANSATES FOR
26E9 20 C4	BRA	\$26AF	* SPKEY DESTROYING A-REG
26EB 81 17	CMP A	##17	* KEY=REPEAT?
26ED 26 08	BNE	\$26F7	
26EF BD 27C0	JSR	SAYDISP	* PRONOUNCE PROBLEM
26F2 BD 27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
26F5 20 08	BRA	\$26FF	
26F7 81 16	CMP A	##16	* KEY=ENTER?
26F9 26 01	BNE	\$26FC	
26FB 39	RTS		* KEY=ENTER THEN RTS
26FC 8D 27E1	JSR	2BEEP	* SAY "GO PLEASE"
26FF DE 44	LDX	TIMER	
2701 20 8A	BRA	\$268D	* START OVER

**** START OF BLANKIT SUBROUTINE ****

2710 96 52	LDA A	MISSING##+1	
2712 CE 000A	LDX	##000A	* THIS ROUTINE BLANKS
2715 81 02	CMP A	##02	* THE MISSING NUMBER IN
2717 2D 0D	BLT	\$2726	* THE DISPLAY BY PUTTING
2719 2E 10	BGT	\$272B	* \$FF IN BUFFER
271B 86 FF	LDA A	##FF	
271D A7 00	STA A	0,X	
271F A7 01	STA A	1,X	
2721 A7 02	STA A	2,X	
2723 A7 03	STA A	3,X	
2725 39	RTS		

```

2726 CE 0006      LDX    $$0006
2729 20 F0        BRA     $271B

272B CE 000E      LDX    $$000E
272E 20 EB        BRA     $271B

```

**** START OF UNPACK SUBROUTINE ****

```

2730 37          PSH B
2731 36          PSH A
2732 84 F0        AND A   $$F0
2734 A7 00        STA A   0,X
2736 32          PUL A
2737 48          ASL A
2738 48          ASL A
2739 48          ASL A
273A 48          ASL A
273B A7 01        STA A   1,X
273D C4 F0        AND B   $$F0
273F E7 02        STA B   2,X
2741 32          PUL A
2742 48          ASL A
2743 48          ASL A
2744 48          ASL A
2745 48          ASL A
2746 A7 03        STA A   3,X
2748 39          RTS

```

* ROUTINE ASSUMES DATA TO
* BE UNPACKED IS IN A:B
* AND FIRST DESTINATION
* ADDRESS IS IN X

* ALSO: NIBBLES ARE PACKED
* INTO LEFT HALF OF BYTES

**** START OF SAYDISP SUBROUTINE ****

```

274A 7D 0061      TST     SAY
274D 27 40        BEQ     $278F
274F C6 01        LDA B   $$01
2751 CE 005B      LDX     $$005B
2754 8D 20        BSR     $2776
2756 96 50        LDA A   OPSIGN
2758 8B 0E        ADD A   $$0E
275A BD 27F6      JSR     SPKWD
275D C6 02        LDA B   $$02
275F CE 005D      LDX     $$005D
2762 8D 12        BSR     $2776

```

* SAY=0 SAY NOTHING
* SAY=1 SAY ALL BUT MISSING#
* SAY=2 SAY ALL
* FIRST DIGIT

* SAY OPERATION (+ - X /)
* LOAD WORD INTO SPEECH BUF.

* 2ND NUMBER

2764 86 22	LDA A	##22	* "EQUALS"
2766 BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2769 C6 03	LDA B	##03	* 3RD NUMBER
276B CE 005F	LDX	##005F	
276E 8D 06	BSR	\$2776	
2770 86 19	LDA A	##19	* 1/2 SEC PAUSE
2772 BD 27F3	JSR	LDPAUS	* LOAD PAUSE INTO SPEECH BUF.
2775 39	RTS		
		* CHKSFK SUBROUTINE	
2776 86 15	LDA A	##15	* 2/5 SEC PAUSE BETWEEN NUMS.
2778 20 16	BRA	\$2790	* LOAD PAUSE
277A 01	NOP		
277B 96 61	LDA A	SAY	
277D 81 02	CMP A	##02	
277F 27 05	BEQ	\$2786	
2781 96 52	LDA A	MISSING#	
2783 11	CBA		
2784 27 04	BEQ	\$278A	* IF = SAY BEEP
2786 BD 27CF	JSR	SAYNUM	* PRONOUNCE PACKED NUM AT (X)
2789 39	RTS		
278A 86 3D	LDA A	##3D	* "LO-TONE"
278C BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
278F 39	RTS		
2790 DF 04	STX	XSAV	
2792 BD 27F3	JSR	LDPAUS	* LOAD PAUSE INTO SPEECH BUF.
2795 DE 04	LDX	XSAV	
2797 20 E2	BRA	\$277B	

**** START OF LINK ****

279A 7E 2ABE	JMP	\$2ABE	* TO TEACH
279D 7E 2924	JMP	\$2924	* TO COMPARE
27A0 7E 2CCF	JMP	\$2CCF	* TO TBLOOK
27A3 7E 2869	JMP	\$2869	* TO GETANS
27A6 7E 2C40	JMP	\$2C40	* TO ADDEM
27A9 7E 281A	JMP	\$281A	* TO BCDMULT
27AC 7E 209F	JMP	\$209F	* TO RANDOM
27AF 20 FD			* STARTING ADDR OF BCDTBL
27B1 7E 2936	JMP	\$2936	* TO GENERATE
27B4 7E 22C7	JMP	\$22C7	* TO BCDADD
27B7 7E 22D6	JMP	\$22D6	* TO BCDINC
27BA 7E 2C00	JMP	\$2C00	* TO ERROR
27BD 7E 291C	JMP	\$291C	* TO BISUB
27C0 7E 274A	JMP	\$274A	* TO SAYDISP
27C3 7E 2710	JMP	\$2710	* TO BLANKIT
27C6 7E 2670	JMP	\$2670	* TO BLANK
27C9 7E 2240	JMP	\$2240	* TO DISPLAY
27CC 7E 2730	JMP	\$2730	* TO UNPACK
27CF 7E 24A7	JMP	\$24A7	* TO SAYNUM

27D2 7E 22F4	JMP	\$22F4	* TO PROGRAM
27D5 7E 2612	JMP	\$2612	* TO GETEM
27D8 7E 2CBF	JMP	\$2CBF	* TO DADD
27DB 7E 28DB	JMP	\$2FAB	* TO PACK
27DE 7E 2469	JMP	\$2469	* TO MINTOBI
27E1 7E 2455	JMP	\$2455	* TO 2BEEP
27E4 7E 2509	JMP	\$2509	* TO CONTINUE (LOCATED IN SCAN)
27E7 7E 268D	JMP	\$268D	* TO GETDIG
27EA 7E 2680	JMP	\$2680	* TO WAIT
27ED 7E 2634	JMP	\$2634	* TO DRILL
27F0 7E 2620	JMP	\$2620	* TO SPKEY
27F3 7E 2602	JMP	\$2602	* TO LDPAUS (LOCATED IN SPKWD)
27F6 7E 2600	JMP	\$2600	* TO SPKWD (SEE LDPAUS)
27F9 7E 2500	JMP	\$2500	* TO SCAN (SEE CONTINUE)
27FC 7E 2A43	JMP	\$2A43	* TO REPORT
27FF 7E 21CA	JMP	\$21CA	* TO HI-LO
2802 7E 22DC	JMP	\$22DC	* TO LOADX
2805 7E 2F80	JMP	\$2F80	* TO RIGHT
2808 7E 211D	JMP	\$211D	* TO OPGEN
280B 2E 00			* ADDTBL STARTING ADDRESS
280D 2E 80			* SUBTBL STARTING ADDRESS
280F 2F 00			* MULT-DIV TBL STARTING ADDRESS

**** START OF BCDMULT SUBROUTINE ****

281A DE 5B	LDX	NUM1	* STORE NUMS IN TEMP VARS.
281C DF 77	STX	UNE	
281E DE 5D	LDX	NUM2	
2820 DF 79	STX	DEUX	
2822 8D 0F	BSR	\$2833	* UNSIGNED BCD MULT.
2824 96 5B	LDA A	NUM1	
2826 98 5D	EOR A	NUM2	* SIGN= SGN1 EXOR SGN2
2828 84 80	AND A	#\$80	
282A 9A 7B	ORA A	TROIX	
282C 97 7B	STA A	TROIX	
282E DE 7B	LDX	TROIX	
2830 DF 5F	STX	NUM3	
2832 39	RTS		
2833 7F 0077	CLR	UNE	* GET RID OF SIGNS
2836 7F 007B	CLR	TROIX	
2839 7F 007C	CLR	TROIX+1	* CLR RUNNING TOTAL
283C 96 7A	LDA A	DEUX+1	
283E 84 0F	AND A	#\$0F	
2840 8D 14	BSR	\$2856	
2842 C6 04	LDA B	#\$04	
2844 96 7A	LDA A	DEUX+1	
2846 5D	TST B		

2847 27 0A	BEQ	\$2853	
2849 78 0078	ASL	UNE+1	
284C 79 0077	ROL	UNE	
284F 44	LSR A		* SHIFT UNE LEFT 4 TIMES
2850 5A	DEC B		* SHIFT A RIGHT 4 TIMES
2851 20 F3	BRA	\$2846	
2853 8D 01	BSR	\$2856	
2855 39	RTS		
2856 4D	TST A		* ADD UNE TO TROIX A TIMES
2857 27 0F	BEQ	\$2868	
2859 36	PSH A		
285A 96 77	LDA A	UNE	
285C D6 78	LDA B	UNE+1	
285E CE 007B	LDX	\$007B	* ADDR OF TROIX
2861 BD 27B4	JSR	BCDADD	* ADD A:B TO LOC @ X
2864 32	PUL A		
2865 4A	DEC A		
2866 20 EE	BRA	\$2856	
2868 39	RTS		

**** START OF GETANS SUBROUTINE ****

2869 8D 20	BSR	\$288B	* FIND ANSWER
286B CE 005B	LDX	\$005B	
286E 8D 0B	BSR	\$287B	* CORRECT ANY OCCURANCE
2870 CE 005D	LDX	\$005D	* OF MINUS ZERO
2873 8D 06	BSR	\$287B	
2875 CE 005F	LDX	\$005F	
2878 8D 01	BSR	\$287B	
287A 39	RTS		
287B A6 00	LDA A	0,X	* MINUS ZERO CHECK SUB.
287D 81 80	CMP A	\$80	
287F 26 09	BNE	\$288A	
2881 A6 01	LDA A	1,X	
2883 4D	TST A		
2884 26 04	BNE	\$288A	
2886 6F 00	CLR	0,X	
2888 6F 01	CLR	1,X	
288A 39	RTS		
288B DE 5B	LDX	NUM1	
288D DF 77	STX	UNE	
288F DE 5D	LDX	NUM2	
2891 DF 79	STX	DEUX	
2893 96 50	LDA A	OPSIGN	
2895 81 11	CMP A	\$11	
2897 2E 11	BGT	\$28AA	* BR IF OPSIGN= TIMES OR DIVIDE
2899 26 06	BNE	\$28A1	* BR IF OPSIGN= ADD


```

289B 20 3F      BRA      $28DC
289D 01         NOP
289E 01         NOP
289F 01         NOP
28A0 01         NOP
28A1 BD 27A6    JSR      ADDEM      * SIGNED BCD ADDITION ROUTINE
28A4 01         NOP
28A5 DE 7B      LDX      TROIX
28A7 DF 5F      STX      NUM3
28A9 39         RTS

28AA BD 27A9    JSR      BCDMULT    * SIGNED BCD MULT. ROUTINE
28AD 96 50      LDA      OPSIGN
28AF 81 12      CMP      #$12      * OPSIGN= MULT.?
28B1 27 F2      BEQ      $28A5
28B3 20 0D      BRA      $28C2
28B5 DE 5D      LDX      NUM2      * FOR DIVISION MOVE NUMBERS
28B7 DF 5F      STX      NUM3      * AFTER DOING MULT.
28B9 DE 5B      LDX      NUM1
28BB DF 5D      STX      NUM2
28BD DE 7B      LDX      TROIX
28BF DF 5B      STX      NUM1
28C1 39         RTS

28C2 DE 5B      LDX      NUM1      * DIVIDE BY ZERO?
28C4 8C 0000    CPX      #$0000
28C7 26 EC      BNE      $28B5
28C9 DE 5D      LDX      NUM2
28CB 8C 0000    CPX      #$0000
28CE 27 05      BEQ      $28D5
28D0 DE 7B      LDX      TROIX
28D2 DF 5F      STX      NUM3
28D4 39         RTS

28D5 CE 0001    LDX      #$0001      * CHANGE PROB TO 0/1=0
28D8 DF 5D      STX      NUM2
28DA 20 D9      BRA      $28B5

28DC 96 48      LDA      MODE      * HERE IF SUBTRACTION
28DE 81 0C      CMP      A #$0C
28E0 26 16      BNE      $28F8      * BR IF MODE NOT EQUAL LEVEL
28E2 96 55      LDA      PROBTYPE
28E4 84 40      AND      A #$40
28E6 27 10      BEQ      $28F8      * BR IF BIT6 NOT SET (T-BIT)
28E8 BD 27A6    JSR      ADDEM      * SIGNED BCD ADDITION ROUTINE
28EB DE 5D      LDX      NUM2
28ED DF 5F      STX      NUM3
28EF DE 5B      LDX      NUM1      * IF HERE: DO SUBTRACTION BY
28F1 DF 5D      STX      NUM2      * DOING ADDITION THEN MOVE SUM
28F3 DE 7B      LDX      TROIX      * TO NUM1, NUM1 TO NUM2, AND
28F5 DF 5B      STX      NUM1      * NUM2 TO NUM3 (NOT IN THAT ORDER)
28F7 39         RTS

28F8 96 79      LDA      A DEUX
28FA 88 80      EOR      A #$80

```

```

28FC 97 79      STA A  DEUX
28FE 20 A1      BRA   $28A1

```

**** START OF BISUB SUBROUTINE ****

```

291C 40          NEG A          * SUB A:B FROM MEM AT X
291D 50          NEG B
291E 82 00      SBC A  #$00
2920 7E 27D8    JMP   DADD      * TWO BYTE BINARY ADD

```

**** START OF COMPARE SUBROUTINE ****

```

2924 DF 79      STX   DEUX      * VALUE-X=TROIX (BCD)
2926 DE 75      LDX   VALUE
2928 DF 77      STX   UNE
292A 96 79      LDA A  DEUX
292C 88 80      EOR A  #$80
292E 97 79      STA A  DEUX
2930 BD 27A6    JSR   ADDEM      * SIGNED BCD ADDITION ROUTINE
2933 DE 7B      LDX   TROIX
2935 39          RTS

```

**** START OF GENERATE SUBROUTINE ****

```

2936 20 0A      BRA   $2942      * BRANCH AROUND PATCH
2938 7D 0055    TST   LOLIM1/PROBTYP
293B 2B 01      BMI   $293E      * IF MSB=1 CHECK THAT
293D 39          RTS              * ABS VAL OF OPERANDS ARE
293E DE 5B      LDX   NUM1        * LESS THAN OR EQUAL TO 30
2940 20 66      BRA   $29A8
2942 96 48      LDA A  MODE
2944 81 0C      CMP A  #$0C
2946 27 38      BEQ   $2980      * BR IF MODE=LEVELS
2948 CE 007D    LDX   #$007D      * ADDR OF SEEDA
294B BD 27AC    JSR   RANDOM      * RANDOM NUMBER GENERATOR
294E DE 53      LDX   LEVEL/HILIM1 * CMP. RANDOM NUM TO LIM
2950 BD 279D    JSR   COMPARE      * COMPARE (BCD) VALUE & X
2953 27 02      BEQ   $2957      * BR IF IN LIMITS
2955 2A F1      BPL   $2948      * BR IF OUT OF LIMITS

```

```

2957 DE 55      LDX      LOLIM1/PROBTYP
2959 BD 279D    JSR      COMPARE      * COMPARE (BCD) VALUE & X
295C 2B EA      BMI      $2948        * BR IF BELOW LIMITS

295E DE 75      LDX      VALUE
2960 DF 5B      STX      NUM1        * MOVE RANDOM NUM

2962 CE 007F    LDX      #$007F      * ADDR OF SEEDB
2965 BD 27AC    JSR      RANDOM      * RANDOM NUMBER GENERATOR
2968 DE 57      LDX      HILIM2
296A BD 279D    JSR      COMPARE      * COMPARE (BCD) VALUE & X
296D 27 02      BEQ      $2971
296F 2A F1      BPL      $2962

2971 DE 59      LDX      LOLIM2
2973 BD 279D    JSR      COMPARE      * COMPARE (BCD) VALUE & X
2976 2B EA      BMI      $2962
2978 DE 75      LDX      VALUE
297A DF 5D      STX      NUM2        * STORE 2ND OPERAND
297C 01         NOP

297D 01         NOP
297E 01         NOP
297F 39         RTS                  * END OF ROUTINE TO
                                     * GET OPERANDS FOR THE
                                     * BOUNDED MODE

2980 96 56      LDA      (LOLIM/PROBTYP)+1
2982 36         FSH      A          * STORE INFO ON 2ND OPERAND
2983 84 F0      AND      A          * MASK OFF ALL BUT 1ST INFO
2985 44         LSR      A
2986 44         LSR      A
2987 44         LSR      A
2988 44         LSR      A
2989 CE 007D    LDX      #$007D      * GENERATE NUM 1 FROM SEEDA
298C BD 2808    JSR      OPGEN      * GENERATE ONE OPERAND
298F DE 75      LDX      VALUE
2991 DF 5B      STX      NUM1

2993 32         PUL      A          * RECOVER INFO ON 2ND OPR.
2994 84 0F      AND      A          *
2996 CE 007F    LDX      #$007F      * GENERATE NUM2 FROM SEEDB
2999 BD 2808    JSR      OPGEN      * GENERATE ONE OPERAND
299C DE 75      LDX      VALUE
299E DF 5D      STX      NUM2

29A0 96 50      LDA      OPSIGN
29A2 81 11      CMP      A          *
29A4 2F 1B      BLE      $29C1      * BR IF ADD OR SUBTRACT
29A6 20 90      BRA      $2938      * BR TO PATCH
29A8 DF 75      STX      VALUE      * TEST IF OPR.'S WITHIN +-30
29AA BD 27FF    JSR      HI-LO      * SET C IF VALUE BETWEEN LIMITS
29AD 00 30      * < +30
29AF 80 30      * > -30
29B1 24 CD      BCC      $2980      * IF OUT OF LIMITS ;NEW PROBLEM

```

```

29B3 DE 5D      LDX    NUM2
29B5 DF 75      STX    VALUE
29B7 BD 27FF    JSR    HI-LO      * CHECK IF NUM2=+-30
                                   * SET C IF VALUE BETWEEN LIMITS
29BA 00 30      * < +30
29BC 80 30      * > -30
29BE 24 C0      BCC    $2980
29C0 39         RTS

29C1 96 55      LDA A  LOLIM1/PROBTYP * IF MSB=1 THEN IGNORE
29C3 84 80      AND A  #$80          * REGROUPING
29C5 26 03      BNE    $29CA
29C7 39         RTS

29C8 20 B4      BRA    $2980
29CA 96 50      LDA A  OPSIGN      * EXOR SIGN BITS WITH LSB
29CC 46         ROR A          * OF OPSIGN, IF MSB OF A =
29CD 46         ROR A          * 0 THEN ADDITION REGROUP
29CE 98 5B      EOR A  NUM1        * 1 THEN SUBTRACT REGROUP
29D0 98 5D      EOR A  NUM2
29D2 84 80      AND A  #$80
29D4 27 3C      BEQ    $2A12

29D6 DE 5B      LDX    NUM1      * HERE FOR SUBTRACTION
29D8 DF 77      STX    UNE
29DA DE 5D      LDX    NUM2
29DC DF 79      STX    DEUX
29DE 7D 005B    TST    NUM1
29E1 2A 08      BPL    $29EB      * BR IF SWAP NOT NEEDED
29E3 DE 5D      LDX    NUM2
29E5 DF 77      STX    UNE      * SWAP UNE & DEUX
29E7 DE 5B      LDX    NUM1      * (DEUX - UNE)
29E9 DF 77      STX    DEUX

29EB D6 7A      LDA B  DEUX+1    * TEST LS NIBBLE FOR
29ED C4 0F      AND B  #$0F      * REGROUPING
29EF 96 78      LDA A  UNE+1
29F1 84 0F      AND A  #$0F
29F3 0C         CLC
29F4 10         SBA
29F5 25 D1      BCS    $29C8
29F7 D6 7A      LDA B  DEUX+1    * TEST TENS NIBBLE
29F9 C4 F0      AND B  #$F0
29FB 96 78      LDA A  UNE+1
29FD 84 F0      AND A  #$F0
29FF 0C         CLC
2A00 10         SBA
2A01 25 C5      BCS    $29C8
2A03 D6 79      LDA B  DEUX      * TEST HUNDREDS NIBBLE
2A05 C4 0F      AND B  #$0F
2A07 96 77      LDA A  UNE
2A09 84 0F      AND A  #$0F
2A0B 0C         CLC
2A0C 10         SBA
2A0D 25 B9      BCS    $29C8
2A0F 39         RTS      * IF HERE THEN NO REGROUPING

```

```

2A10 01      NOP
2A11 01      NOP

2A12 D6 5C      LDA B  NUM1+1      * TEST FOR ADD'N REGROUPING
2A14 C4 0F      AND B  #$0F
2A16 96 5E      LDA A  NUM2+1      * TEST LS NIBBLE
2A18 84 0F      AND A  #$0F
2A1A 8A 90      ORA A  #$90      * 9 PROPAGATES CARRY
2A1C 1B        ABA
2A1D 19        DAA
2A1E 25 A8      BCS    $29C8
2A20 D6 5C      LDA B  NUM1+1      * TEST TENS NIBBLE
2A22 C4 F0      AND B  #$F0
2A24 96 5E      LDA A  NUM2+1
2A26 84 F0      AND A  #$F0
2A28 1B        ABA
2A29 19        DAA
2A2A 25 9C      BCS    $29C8
2A2C D6 5B      LDA B  NUM1      * TEST HUNDREDS NIBBLE
2A2E C4 0F      AND B  #$0F
2A30 96 5D      LDA A  NUM2
2A32 84 0F      AND A  #$0F
2A34 8A 90      ORA A  #$90
2A36 1B        ABA
2A37 19        DAA
2A38 25 8E      BCS    $29C8
2A3A 39        RTS      * IF HERE THEN NO REGROUPING

```

**** START OF REPORT SUBROUTINE ****

```

2A43 BD 27C6      JSR    BLANK      * BLANK ENTIRE DISPLAY

2A46 DE 64      LDX    ATTPROBS
2A48 DF 77      STX    UNE      * TOTAL-#WRONG=#RIGHT
2A4A 96 66      LDA A  WRONG
2A4C 8A 80      ORA A  #$80      * CHANGE SIGN TO MINUS
2A4E 97 79      STA A  DEUX
2A50 96 67      LDA A  WRONG+1
2A52 97 7A      STA A  DEUX+1
2A54 BD 27A6      JSR    ADDEM      * SIGNED BCD ADDITION ROUTINE

2A57 86 2E      LDA A  #$2E      * "TOTAL"
2A59 BD 27F6      JSR    SPKWD      * LOAD WORD INTO SPEECH BUF.

2A5C 96 7B      LDA A  TROIX
2A5E D6 7C      LDA B  TROIX+1      * A:B=#RIGHT
2A60 CE 0006      LDX    #$0006      * BUFFER ADDR FOR FIRST DISPLAY
2A63 BD 27CC      JSR    UNPACK      * SEPERATE NIBBLES INTO BYTES

2A66 CE 007B      LDX    #$007B      * ADDR OF TROIX
2A69 BD 27CF      JSR    SAYNUM      * PRONOUNCE PACKED NUM AT (X)

```

2A6C 86 21	LDA A	##21	* "OVER"
2A6E BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2A71 96 64	LDA A	ATTPROBS	
2A73 D6 65	LDA B	ATTPROBS+1	
2A75 CE 000A	LDX	##000A	* BUFFER ADDR OF 2ND DISPLAY
2A78 BD 27CC	JSR	UNPACK	* SEPERATE NIBBLES INTO BYTES
2A7B 86 EE	LDA A	##EE	* CODE FOR DIVISION SIGN
2A7D 97 12	STA A	\$0012	* PUFFER FOR OPERATION SIGN
2A7F CE 0064	LDX	##0064	* ADDR OF NO. ATTEMPTED
2A82 BD 27CF	JSR	SAYNUM	* PRONOUNCE PACKED NUM AT (X)
2A85 86 65	LDA A	##65	* 2 SECOND PAUSE
2A87 BD 27F3	JSR	LDPAUS	* LOAD PAUSE INTO SPEECH BUF.
2A8A BD 27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
2A8D BD 27C6	JSR	BLANK	* BLANK ENTIRE DISPLAY
2A90 96 6A	LDA A	MINUTES	
2A92 D6 6B	LDA B	MINUTES+1	
2A94 CE 0006	LDX	##0006	* FIRST DISP. ADDR BUFFER
2A97 BD 27CC	JSR	UNPACK	* SEPERATE NIBBLES INTO BYTES
2A9A CE 006A	LDX	##006A	* ADDR OF MINUTES
2A9D BD 27CF	JSR	SAYNUM	* PRONOUNCE PACKED NUM AT (X)
2AA0 86 27	LDA A	##27	* "AND"
2AA2 BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2AA5 96 68	LDA A	SECONDS	
2AA7 D6 69	LDA B	SECONDS+1	
2AA9 CE 000A	LDX	##000A	* ADDR OF 2ND DISP. BUFFER
2AAC BD 27CC	JSR	UNPACK	* SEPERATE NIBBLES INTO BYTES
2AAF CE 0068	LDX	##0068	* ADDR OF SECONDS
2AB2 BD 27CF	JSR	SAYNUM	* PRONOUNCE PACKED NUM AT (X)
2AB5 86 28	LDA A	##28	* "SECONDS"
2AB7 BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2ABA BD 27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
2ABD 39	RTS		

**** START OF TEACH SUBROUTINE ****

2ABE 20 40	BRA	\$2B00	* BRANCH AROUND SUB.
2AC0 BD 27DB	JSR	PACK	* PACK MULTIDIGIT INFO

2AC3 96 44	LDA A	TIMER	
2AC5 D6 45	LDA B	TIMER+1	* ALLOWED-TIME LEFT=
			* TIME TAKEN
2AC7 CE 006D	LDX	#\$006D	* ADDR OF DISPTIM
2ACA BD 27BD	JSR	BISUB	* UNSIGNED BINARY SUBTRACTION
2ACD DE 6D	LDX	DISPTIM	
2ACF 08	INX		* CORRECT TIME TAKEN
2AD0 DF 6D	STX	DISPTIM	
2AD2 86 00	LDA A	#\$00	* SUBTRACT 50 (\$32) FROM TIME
2AD4 C6 32	LDA B	#\$32	* TAKEN TO GET SEC (DIV. BY 50)
2AD6 CE 006D	LDX	#\$006D	
2AD9 BD 27BD	JSR	BISUB	* UNSIGNED BINARY SUBTRACTION
2ADC 24 1F	BCC	\$2AFD	* RETURN IF RESULT NEG.
2ADE CE 0068	LDX	#\$0068	* ADDR OF SECONDS
2AE1 BD 27B7	JSR	BCDINC	* INCREMENT (BCD) AT X & X+1
2AE4 DE 68	LDX	SECONDS	
2AE6 8C 0060	CPX	#\$0060	
2AE9 26 0B	BNE	\$2AF6	
2AEB CE 0000	LDX	#\$0000	
2AEE DF 68	STX	SECONDS	
2AF0 CE 006A	LDX	#\$006A	* ADDR OF MINUTES
2AF3 BD 27B7	JSR	BCDINC	* INCREMENT (BCD) AT X & X+1
2AF6 DE 71	LDX	BINSECS	
2AF8 08	INX		
2AF9 DF 71	STX	BINSECS	
2AFB 20 D5	BRA	\$2AD2	
2AFD 39	RTS		
2AFE 20 C0	BRA	\$2AC0	* STEPPING STONE
2B00 DE 4A	LDX	SEED1	
2B02 DF 7D	STX	SEED1A	* TRANSFER SEEDS TO START
2B04 DE 62	LDX	SEED2	* PROBLEM SETS
2B06 DF 7F	STX	SEEDB	
2B08 CE 0000	LDX	#\$0000	
2B0B DF 68	STX	SECONDS	* CLEAR COUNTERS
2B0D DF 6A	STX	MINUTES	
2B0F DF 64	STX	ATTPROBS	
2B11 DF 71	STX	BINSECS	
2B13 DF 66	STX	WRONG	
2B15 86 01	LDA A	#\$01	* SET SAY SO PROBLEMS
2B17 97 61	STA A	SAY	* WITHOUT ANSWERS ARE SAID.
2B19 7F 006C	CLR	ERROR	
2B1C 8D 75	BSR	\$2B93	* GENERATE NEW PROBLEM & ANS.
2B1E 01	NOP		
2B1F BD 27C0	JSR	SAYDISP	* PRONOUNCE PROBLEM
2B22 01	NOP		
2B23 01	NOP		
2B24 01	NOP		
2B25 BD 27C9	JSR	DISPLAY	* LOAD PROB. INTO DISPLAY
2B28 BD 27C3	JSR	BLANKIT	* BLANK MISSING NO. IN DISP.
2B2B CE FFFE	LDX	#\$FFFE	* IF OPTION NOT SPEED THEN
2B2E 96 49	LDA A	OPTION	* DISPTIM=MAX ELSE TIMLIM.
2B30 81 0E	CMP A	#\$0E	* =SPEED?

2B32 26 02	BNE	\$2B36	
2B34 DE 4C	LDX	TIMLIM	
2B36 DF 6D	STX	DISPTIM	
2B38 7F 0014	CLR	\$0014	* PROMPT KEYBOARD
2B3B BD 27E7	JSR	GETDIG	* GO GET DIGITS FROM KEYBOARD
2B3E CE 006F	LDX	#\$006F	* ADDR OF ANSWER
2B41 8D BB	BSR	\$2AFE	* UPDATE TIME INFO
2B43 01	NOP		
2B44 CE 005B	LDX	#\$005B	* PUT ADDR OF CORRECT ANS.
2B47 86 01	LDA A	#\$01	* IN X REG
2B49 91 52	CMP A	MISSING#	
2B4B 27 06	BEQ	\$2B53	
2B4D 4C	INC A		
2B4E 08	INX		
2B4F 08	INX		
2B50 20 F7	BRA	\$2B49	
2B52 01	NOP		
2B53 EE 00	LDX	0,X	
2B55 9C 6F	CPX	ANSWER	* COMPARE STUDENTS ANS. &
2B57 27 41	BEQ	\$2B9A	* CORRECT ANSWER
2B59 BD 27BA	JSR	ERROR	* APPLY NEG. FEEDBACK
2B5C 7D 006C	TST	ERROR	* IF ERROR =0 THEN TRY AGAIN
2B5F 24 07	BNE	\$2B68	
2B61 7C 006C	INC	ERROR	
2B64 20 B9	BRA	\$2B1F	* ASK AGAIN
2B66 20 AD	BRA	\$2B15	* STEPPING STONE TO NEW PROBLEM
2B68 CE 0066	LDX	#\$0066	* ADDR OF WRONG
2B6B BD 27B7	JSR	BCDINC	* INCREMENT (BCD) AT X & X+1
2B6E 7C 0061	INC	SAY	* ENABLE SAYING OF ANSWER
2B71 86 19	LDA A	#\$19	* 1/2 SECOND PAUSE
2B73 BD 27F3	JSR	LDFAUS	* LOAD PAUSE INTO SPEECH BUF.
2B76 BD 27C0	JSR	SAYDISP	* PRONOUNCE PROBLEM
2B79 BD 27C9	JSR	DISPLAY	* LOAD PROB. INTO DISPLAY
2B7C BD 27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
2B7F CE 00FA	LDX	#\$00FA	* 5 SEC PAUSE
2B82 BD 27F9	JSR	SCAN	* INPUT:KEYS OUTPUT:DISP. & TALK
2B85 96 00	LDA A	KEY	
2B87 81 17	CMP A	#\$17	* KEY = REPEAT?
2B89 27 EB	BEQ	\$2B76	
2B8B CE 0064	LDX	#\$0064	* ADDR OF ATTPROB
2B8E BD 27B7	JSR	BCDINC	* INCREMENT (BCD) AT X & X+1
2B91 20 33	BRA	\$2B06	* TEST FOR END CONDITIONS
2B93 20 0A	BRA	\$2B9F	* STEPPING STONE
2B95 01	NOP		
2B96 01	NOP		
2B97 01	NOP		
2B98 01	NOP		
2B99 01	NOP		

2B9A BD 2805	JSR	RIGHT	* APPLY POSITIVE FEEDBACK
2B9D 20 CF	BRA	\$2B6E	* GIVE ANSWER TO STUDENT
2B9F BD 27B1	JSR	GENERATE	* GENERATE PROBLEM
2BA2 BD 27A3	JSR	GETANS,	* FIND CORRECT ANSWER
		* TEST FOR: $N \times 0 = 0$	
		* $0 \times N = 0$	
		* $0 / N = 0$	
2BA5 96 52	LDA A	MISSING#	
2BA7 81 03	CMP A	#\$03	* MISSING NO.=3?
2BA9 26 01	BNE	\$2BAC	
2BAB 39	RTS		
2BAC 96 50	LDA A	OPSIGN	
2BAE 84 02	AND A	#\$02	
2BB0 26 01	BNE	\$2BB3	* BR IF MULT OR DIV
2BB2 39	RTS		
2BB3 DE 5B	LDX	NUM1	
2BB5 27 EB	BEQ	\$2B9F	* IF NUM1=0 GET NEW PROB.
2BB7 DE 5D	LDX	NUM2	
2BB9 27 E4	BEQ	\$2B9F	* IF NUM2=0 GET NEW PROB.
2BBB 39	RTS		
2B9C 01	NOP		
2BBD 01	NOP		
2BBE 01	NOP		
2BBF 01	NOP		
2BC0 01	NOP		
2BC1 01	NOP		
2BC2 01	NOP		
2BC3 01	NOP		
2BC4 01	NOP		
2BC5 01	NOP		
2BC6 96 49	LDA A	OPTION	* TEST EXIT CONDITIONS
2BC8 81 0D	CMP A	#\$0D	
2BCA 26 11	BNE	\$2BDD	* OPTION = POWER?
2BCC DE 71	LDX	BINSECS	* BINSECS-TIMLIM=TIMER
2BCE DF 44	STX	TIMER	
2BD0 96 4C	LDA A	TIMLIM	
2BD2 D6 4D	LDA B	TIMLIM+1	
2BD4 CE 0044	LDX	#\$0044	
2BD7 BD 27BD	JSR	BISUB	* UNSIGNED BINARY SUBTRACTION
2BDA 24 8A	BCC	\$2B66	* BR IF TIMLIMIT NOT EXCEEDED
2BDC 39	RTS		
2BDD DE 4E	LDX	MAXPROBS	* TEST IF ALL PROBS DONE
2BDF 9C 64	CPX	ATTPROBS	
2BE1 26 83	BNE	\$2B66	
2BE3 39	RTS		

**** START OF ERROR SUBROUTINE ****

2C00 BD 27EA	JSR	WAIT	* WAIT TILL SPEECH-BUF EMPTY
2C03 86 01	LDA A	##01	* # OF TONE PAIRS
2C05 97 42	STA A	DIG5	
2C07 86 0A	LDA A	##0A	* # OF DISPLAY BLINKS
2C09 97 43	STA A	DIG6	
2C0B 8D 0D	BSR	\$2C1A	* SOUND TONES
2C0D 7A 0042	DEC	DIG5	
2C10 26 00	BNE	\$2C12	
2C12 8D 11	BSR	\$2C25	* BLINK DISPLAY
2C14 7A 0043	DEC	DIG6	
2C17 26 F9	BNE	\$2C12	
2C19 39	RTS		
2C1A 86 3E	LDA A	##3E	* "HI TONE"
2C1C BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2C1F 86 3E	LDA A	##3E	* "HI TONE"
2C21 BD 27F6	JSR	SPKWD	* LOAD WORD INTO SPEECH BUF.
2C24 39	RTS		
2C25 BD 27C6	JSR	BLANK	* BLANK ENTIRE DISPLAY
2C28 CE 0005	LIX	##0005	* 1/10 SECOND PAUSE
2C2B BD 27F9	JSR	SCAN	* INPUT:KEYS OUTPUT:DISP. & TALK
2C2E BD 27C9	JSR	DISPLAY	* LOAD PROB. INTO DISPLAY
2C31 BD 27C3	JSR	BLANKIT	* BLANK MISSING NO. IN DISP.
2C34 CE 0005	LIX	##0005	* 1/10 SECOND PAUSE
2C37 BD 27F9	JSR	SCAN	* INPUT:KEYS OUTPUT:DISP. & TALK
2C3A 39	RTS		

**** START OF ADDEM SUBROUTINE ****

2C40 DE 77	LIX	UNE	* CHECK FOR MINUS ZERO
2C42 8C 8000	CPX	##8000	* IN UNE AND DEUX
2C45 26 05	BNE	\$2C4C	
2C47 CE 0000	LIX	##0000	
2C4A DF 77	STX	UNE	
2C4C DE 79	LIX	DEUX	
2C4E 8C 8000	CPX	##8000	
2C51 26 05	BNE	\$2C58	
2C53 CE 0000	LIX	##0000	
2C56 DF 79	STX	DEUX	
2C58 96 77	LDA A	UNE	
2C5A 98 79	EOR A	DEUX	

2C5C 2A 22	BPL \$2C80	* BR IF SIGNS SAME
2C5E CE 0077	LDX #\$0077	* ADDR OF UNE
2C61 8D 4B	BSR \$2CAE	* NEGATE (10'S COMP) IF NEG.
2C63 CE 0079	LDX #0079	* ADDR OF DEUX
2C66 8D 46	BSR \$2CAE	* NEGATE (10'S COMP) IF NEG.
2C68 96 77	LDA A UNE	
2C6A D6 78	LDA B UNE+1	* SET UP FOR ADD
2C6C DE 79	LDX DEUX	
2C6E DF 7B	STX TROIX	
2C70 CE 007B	LDX #\$007B	* ADDR OF TROIX
2C73 BD 27B4	JSR BCDADD	* ADD A:B TO LOC @ X
2C76 24 01	BCC \$2C79	* IF C=1 THEN ANS. IS POS.
2C78 39	RTS	
2C79 8D 23	BSR \$2C9E	* NEGATE ANS. (10'S COMP)
2C7B 8A 80	ORA A #\$80	* SET SIGN BIT
2C7D A7 00	STA A 0,X	
2C7F 39	RTS	
2C80 96 77	LDA A UNE	* HERE IF SIGNS SAME
2C82 36	PSH A	
2C83 84 7F	AND A #\$7F	* TAKE ABS VALUE
2C85 97 77	STA A UNE	
2C87 96 79	LDA A DEUX	
2C89 84 7F	AND A #\$7F	* TAKE ABS VALUE
2C8B D6 7A	LDA B DEUX+1	
2C8D DE 77	LDX UNE	
2C8F DF 7B	STX TROIX	* SET UP FOR ADD
2C91 CE 007B	LDX #\$007B	* ADDR OF TROIX
2C94 BD 27B4	JSR BCDADD	* ADD A:B TO LOC @ X
2C97 33	FUL B	* RECOVER SIGN
2C98 C4 80	AND B #\$80	* MASK ALL BUT SIGN
2C9A 1B	ABA	* TFR SIGN TO ANSWER
2C9B 97 7B	STA A TROIX	
2C9D 39	RTS	
2C9E 86 99	LDA A #\$99	* 10'S COMP SUBROUTINE
2CA0 A0 01	SUB A 1,X	
2CA2 A7 01	STA A 1,X	* FORM 9'S COMP FIRST
2CA4 86 99	LDA A #\$99	
2CA6 A2 00	SBC A 0,X	
2CA8 A7 00	STA A 0,X	* INC TO GET 10'S COMP
2CAA BD 27B7	JSR BCDINC	* INCREMENT (BCD) AT X & X+1
2CAD 39	RTS	
2CAE 6D 00	TST 0,X	* IF VALUE AT X IS NEGATIVE
2CB0 2A FB	BPL \$2CAD	* THEN DO 10'S COMP
2CB2 A6 00	LDA A 0,X	* ELSE RTS
2CB4 84 0F	AND A #\$0F	
2CB6 A7 00	STA A 0,X	
2CB8 20 E4	BRA \$2C9E	

**** START OF DADD SUBROUTINE ****

```

2CBF EB 01      ADD B 1,X          * ADD A:B TO VALUE AT X
2CC1 E7 01      STA B 1,X
2CC3 A9 00      ADC A 0,X
2CC5 A7 00      STA A 0,X
2CC7 39         RTS

```

**** START OF TBLOOK SUBROUTINE ****

```

2CCF 96 48      LDA A MODE
2CD1 81 0C      CMP A #$0C          * MODE=LEVEL OF DIF.?
2CD3 27 01      BEQ $2CD6
2CD5 39         RTS

2CD6 96 50      LDA A OPSIGN
2CD8 CE 280B    LDX $280B          * LOAD ADDR POINTING TO
                                   * STARTING ADDR OF ADDBL IN LINK
2CDB 81 10      CMP A #$10
2CDD 27 08      BEQ $2CE7          * OPERATION=ADD?
2CDF 08         INX
2CE0 08         INX              * X NOW POINTS TO ADDR OF
                                   * SUBTBL IN LINK
2CE1 81 11      CMP A #$11
2CE3 27 02      BEQ $2CE7          * OPERATION=SUB?
2CE5 08         INX
2CE6 08         INX              * POINT X AT M-DTBL ADDR
2CE7 EF 00      LDX 0,X           * RETRIEVE STARTING ADDR
                                   * OF LOOK UP TABLE
2CE9 DF 04      STX XSAV
2CEB CE 0001    LDX $0001          * INITIALIZE BCD COUNTER
2CEE DF 55      STX LOLIM1/PROBTYP

2CF0 DE 04      LDX XSAV
2CF2 EE 00      LDX 0,X           * IF END OF TABLE FOUND (FFFF)
2CF4 8C FFFF    CPX $FFFF          * THEN RESTART MACHINE!
2CF7 26 03      BNE $2CFC
2CF9 7E 2000    JMP $2000

2CFC DE 55      LDX LOLIM1/PROBTYP
2CFE 9C 53      CPX LEVEL/HILIM1  * BR IF COUNTER=LEVEL
2D00 27 0E      BEQ $2D10
2D02 DE 04      LDX XSAV          * INC FOR NEXT PASS
2D04 08         INX
2D05 08         INX
2D06 DF 04      STX XSAV
2D08 CE 0055    LDX $0055          * ADDR OF BCD COUNTER
2D0B 8D 27B7    JSR BCDINC        * INCREMENT (BCD) AT X & X+1
2D0E 20 E0      BRA $2CF0

2D10 DE 04      LDX XSAV          * IF LEVEL=COUNTER THEN

```

```

2D12 EE 00      LDX      0,X          * GET ITEM FROM TABLE
2D14 DF 55      STX      LOLIM1/PROBTYP
2D16 39         RTS

```

**** START OF ADDBL ****

```

2E00 00 00
      00 02      * DATA FORMAT:
      00 20      *      [ OPTION BYTE ]:[ OPERAND BYTE ]
      00 22      *
      00 44      * WHERE [ OPTION BYTE ] IS OF THE FORMAT:
      00 64      * [ RXXXXXXX ]
      00 46      *
      00 66      * WHERE R IS THE REGROUPING BIT
      80 84      * IT IS SET IF REGROUPING IS NOT ALLOWED
      80 48      * IN PROBLEM SET.
      00 84      * WHERE X IS A 'DON'T CARE' BIT.
      00 48      *
      80 88      * WHERE [ OPERAND BYTE ] IS OF THE FORMAT:
      00 88      * [ NIBBLE1 : NIBBLE2 ]
      80 B4      *
      80 4B      * NIBBLE1 DEFINES THE FIRST OPERAND.
      00 B4      * NIBBLE2 DEFINES THE SECOND OPERAND.
      00 4B      *
      80 B8      * IF NIBBLE CONTAINS; THEN OPERAND IS
      80 3B      * [0]; FROM 0 TO 4
      00 B8      * [1]; FROM -4 TO 4
      00 8B      * [2]; FROM 5 TO 9
      80 BB      * [3]; FROM -9 TO -5 AND 5 TO 9
      00 BB      * [4]; FROM 0 TO 9
      00 BD      * [5]; FROM -9 TO 9
      00 DB      * [6]; 0,10,20, . . . ,90
      00 DD      * [7]; -90,-80,-70, . . . ,70,80,90
      FF FF      * [8]; FROM +10 TO +99
      FF FF      * [9]; FROM -99 TO -10 AND +10 TO +99
                  * [A]; FROM -99 TO 99
                  * [B]; FROM +100 TO +499
                  * [C]; FROM -499 TO -100 AND +100 TO +499
                  * [D]; FROM -499 TO +499
                  *
                  * THE TABLE ENDS WITH THE SIGNAL FFFF

```

**** START OF SUBTBL ****

```

2E80 40 00      * THE DATA IS OF THE FORMAT:
      40 02      * [ OPTION BYTE ]:[ OPERAND BYTE ]
      40 20      *
      40 22      * WHERE [ OPTION BYTE ] IS OF THE FORMAT:
      40 44      * [ RTXX XXXX ]
      80 88      *

```

```

00 64
00 84
00 88
80 B4
00 B4
80 B8
00 B8
80 B8
00 B8
00 45
00 54
00 55
00 DD
FF FF
FF FF

```

*

```

* R IS THE REGROUPING BIT.
* T IS SET IF THE SUBTRACTION PROBLEM
* IS TO BE GENERATED BY ADDITION AND THE
* NUMBERS MOVED SO THAT THE SUM IS LOCATED
* IN THE FIRST POSITION.

* THE [ OPERAND BYTE ] IS DEFINED AS IN
* ADDITION TABLE

```

**** START OF M-DTBL ****

```

2F00 00 00
00 04
00 40
00 44
00 64
00 46
00 48
00 84
80 88
00 45
00 54
80 AA
FF FF
FF FF

```

*

```

* DATA IS OF THE FORMAT:
* [ OPTION BYTE ]:[ OPERAND BYTE ]
* WHERE [ OPTION BYTE ] IS OF THE FORMAT
* [ LXXX XXXX ]
* IF L IS SET THE OPERANDS ARE BETWEEN
* -30 AND +30
* THE [ OPERAND BYTE ] IS DEFINED AS IN
* ADDITION TABLE EXCEPT THAT DIVISION IS
* DONE BY MULTIPLYING FIRST AND SECOND
* OPERANDS AND THEN MOVING THE NUMBERS
* TO FORM THE COMPLEMENTARY DIVISION
* PROBLEM.

```

**** START OF BLANK SUBROUTINE ****

```

2F70 86 FF      LDA A  #$FF
2F72 CE 0006    LDX   #$0006
2F75 8C 0016    CFX   #$0016
2F78 26 01      BNE   $2F7B
2F7A 39         RTS
2F7B A7 00      STA A  0,X
2F7D 08         INX
2F7E 20 F5      BRA   $2F75

```

*

```

* THIS ROUTINE PUTS $FF IN
* DISPLAY BUFFER LOCATIONS

```

*** START OF PACK SUBROUTINE ***

```

2FAB 96 3F      LDA A  DIG2

```

```

2FAD 48      ASL A
2FAE 48      ASL A
2FAF 48      ASL A
2FB0 48      ASL A
2FB1 9A 3E    ORA A DIG1
2FB3 A7 01    STA A 1,X
2FB5 96 3D    LDA A SGNDIG
2FB7 84 80    AND A #$80
2FB9 9A 40    ORA A DIG3
2FBB A7 00    STA A 0,X
2FBD 7D 003D  TST SGNDIG
2FC0 26 06    BNE $2FC8
2FC2 A6 00    LDA A 0,X
2FC4 8A 80    ORA A #$80
2FC6 A7 00    STA A 0,X
2FC8 39      RTS

```

* FINAL FORMAT OF PACKED DATA
 * /SXXX/HUND'S/ /TENS/ONES/
 * WHERE S=SIGN BIT (1=MINUS)

* MASK OFF ALL BUT SIGN BIT

* SET SIGN BIT IF GETDIGIT
 * TIMES OUT WITH NO ENTRY

**** START OF RIGHT SUBROUTINE ****

```

2F80 86 FF    LDA A #$FF
2F82 97 14    STA A $0014
2F84 86 3D    LDA A #$3D
2F86 BD 2786  JSR SPKWD
2F89 86 3D    LDA A #$3D
2F8B BD 2786  JSR SPKWD
2F8E 86 3D    LDA A #$3D
2F90 BD 2786  JSR SPKWD
2F93 BD 27EA  JSR WAIT
2F96 39      RTS

```

* TURN OFF PROMPT

* "LO TONE"

* LOAD WORD INTO SPKBUF

* "LO TONE"

* LOAD WORD INTO SPKBUF

* "LO TONE"

* LOAD WORD INTO SPKBUF

* WAIT UNTIL SPKBUF EMPTY

**** RESTART AND INTERRUPT VECTORS ****

```

2FF8 20 27    * INTERRUPT VECTOR
2FFA 20 00    * SWI VECTOR
2FFC 20 00    * NON-MASKABLE INTERRUPT VECTOR
2FFE 20 00    * RESTART VECTOR

```

```

*****
****      END OF CONTROL PROGRAMS      ****
*****

```

APPENDIX IV

PROCEDURE FOR BURNING EPROMs

The 2708 EPROMs were programmed using a PRO-LOG M900 Universal PROM Programmer, equipped with a model 9115 RS232 interface. The programmer was controlled by a D2 microcomputer having a 4K RAM board. The D2 kit was interfaced to the programmer via a standard 25 pin communications connector and the circuit shown in Fig. 1. After loading the 4K RAM with the data to be programmed, the EPROM burning program, shown herein, was loaded. The addresses of the beginning and end of the data block were entered into memory at locations \$0000-\$0003. The PROLOG was reset and the program was executed starting at \$0004.

FIGURE 1 - D2 to Prolog Interface

MAIN			NOTE: St. Addr. of Block \$0000-01, End Addr. of Block - \$0002-03	
\$0004	JSR INITIALIZE	BD,00,92		
	LDAA,\$30	86,30	"0"	
	JSR OUTCR	BD,00,7F		
	LDA \$30	86,33	"0"	Supply EPROM Address Range
	JSR OUTCR	BD,00,7F		
	LDA \$46	86,46	"F"	
	JSR OUTCR	BD,00,7F		
	LDA \$46	86,46	"F"	
	JSR OUTCR	BD,00,7F		
LOOP	LDA \$50	86,50	"P"	(Start Program Mode)
	JSR OUTCR	BD,00,7F		
	LDX START	DE,00		
	LDAAX,0	A6,00		
	JSR OUTBYTE	BE,00,52		
				Output Data
	LDX START	DE,00		
	CPX END	9C,02		
	BEQ EXIT	27,05		
EXIT	INX	08		
	STX START	DF,00		Move Pointer
	BRA LOOP	20,EE		
	LDA \$04	86,04	"EOT"	
	JSR OUTCR	BD,00,7F		
	SWI	3F(at \$0041)		
	(\$0042) CMPA \$09	81,09		
	BGT{AF}	2E,06		
	ADD A \$30	8B,30	\$0+\$30=\$30="0"	
(4C)AF	JSR OUTCR	BD,00,7F		
	RTS	39		
	ADD A \$47	8B,37	\$37+\$0A=\$41="A"	
	JSR OUTCR	BD,007F		
	RTS	39	AT \$0051	
(\$0052) OUTBYTE	PUSH A	36		
	LSR A	44		
	LSR A	44		
	LSR A	44		
	LSR A	44		
	JSR HEXOUT	BD,00,42		
	PULL A	32		
	AND A, \$0F	84,0F		
	JSR HEXOUT	BD,00,42		
(\$0070) OUTCH	RTS	39	AT \$0060	
	PUSH B	37	SEND	
	JSR PATCH	BD,00,A4	CHARACTER WHEN	
	ASR B	57	PROLOG IS	
	ASR B	57	READY	

	BCC	24,F9	(i.e., $\overline{\text{CTS}}=+12\text{V}$)
	LDA B \$8004	F6,80,04	
	ASR B	57	
	BCS	25,F3	
	STA A,\$8009	B6,80,09	SEND!
	PULL B	33	
(\$0091)	RTS	39	
(\$0092)			
INITIALIZE	LD A A,#881	86, 81	
	ST A A,\$8008	B7,80,08	
	LD A A#\$00	86,00	
	ST A A,\$8004	B6,80,08	
	LDA A,\$04	86,04	
	STA A,\$8005	B6,80,05	
(\$00A1)	RTS	39	
(\$00A4)			
PATCH	LDX \$0FFF	CE,0F,FF	
	DEX	09	DELAY
	BNE {PATCH}	26,FD	
	LDA B,\$8008	F6,80,08	
(\$00AD)	RTS	39	

APPENDIX V

USERS MANUAL

A. Device Overview

The Mathematics Trainer has been designed to tutor a visually handicapped student in the four basic arithmetic operations: addition, subtraction, multiplications, and division. The device uses speech in order to present the student with an incomplete mathematical sentence such as "three plus two equals blank". The student will use a numeric keypad to enter the number that should be in the blank. A sketch of the Trainer is shown in Figs. 1 and 2. The device will inform the student of the responses's correctness. If the answer is incorrect, the device will repeat the problem. If the student fails to enter the correct response the second time, the device will inform the student of the response's incorrectness and will speak the entire problem with the correct answer in its proper place. If the student's answer is correct, the device will indicate that the response is correct and speak the complete mathematical sentence with the answer in place. After each problem, the device records the correctness of the student's answer and the amount of time that it took the student to respond. After the student has completed all of the problems that the teacher has assigned, the device reports the number of correct answers, the total number of problems attempted, and the total response time saying, "TOTAL[number right] OVER[number attempted]" pausing, and then saying "[number of minutes]

FIGURE 1 - Math Trainer Layout

CHOICE OF METHOD
OF DEFINING PROBLEM
SETS ENTERED HERE

FIGURE 2 - Keyboard Detail. Prompt labels are in both print and braille.

AND[number of seconds] SECONDS and STOP".

The teacher is able to select how the problems will be presented to the student. Problem sets may be setup on the basis of 1) a Timed mode, with a maximum total response time, 2) a Power mode, with a fixed number of problems and unlimited time, or 3) a Speed mode where the student has a fixed amount of time per problem and a fixed number of problems in the problem set.

The teacher is also able to define the contents of the problem sets. In addition to specifying the operation involved (addition, subtraction, multiplication, or division), the teacher can delimit the problem sets using two different modes. In the Level mode, (L key), the teacher supplies the device with the level of difficulty desired. In the Range mode, (R key), the teacher supplies the upper and lower bounds on the two operands needed to define the problem. The problems are generated randomly within a given problem set. In addition, each problem set is repeatable, by pushing REPEAT after the machine says "STOP". A discussion of the choices made with regard to problem set generation, as well as Learning modes, is presented in the following sections.

B. Problem Generation

1. Range Mode

In the Range mode, the teacher defines the problem set by keying in the upper and lower limits for each of the first two numbers (operands) in the problem. The device randomly generates a number between or equal to these higher and lower limits. These random numbers become the actual values used in the problem. However,

in division, the limits refer to the second and third numbers (i.e., the divisor and the quotient).

This mode allows the teacher to tailor problem sets to a student's specific needs. If, for example, a student is having trouble solving problems involving multiplications by three, the teacher could have the device present only problems that have three as the second number. This could be accomplished by setting both of the limits of the second number equal to three.

2. Level of Difficulty Mode

In the level of difficulty mode, the teacher supplies a level number to the device; that number corresponds to a specific predefined problem set. Those problem sets are arranged so that, for a given operation, they are progressively more difficult as the level number increases.

The teacher needs only to increment the level number, after the student becomes proficient in the present level, in order to proceed sequentially to the next more difficult problem set. Of course, the teacher must train the student in the mathematical mechanics necessary for each problem set.

In selecting the problem set for each level, every effort was made to present the computational concepts in the same order as is currently employed in the elementary schools. One of the major determinants of problem set difficulty is the presence of problems that involve regrouping. Regrouping is a term to denote the occurrence of a carry in addition or a borrow in subtraction. The device will discriminate between problems that have regrouping for addition and subtraction. (The problem set definitions for addition and subtraction

are shown in TABLES 1 and 2). Because division is normally taught as the conceptual inverse of multiplication, it was decided that the division problem sets would be the inverses of the multiplication problem sets (see TABLE 3).

C. Problem and Answer Presentation

This device is designed to be used by students in elementary school; therefore, the problem sets are limited to integer arithmetic. Since integers are not closed under division, only problems that have integer quotients are generated.

Often, problems that are presented in the students' text books, have the missing number in positions other than to the right of the equals sign. Because of this, the device will allow the teacher to change the position of the missing number to correspond to any of the three positions in the problem sentence. The three positions are numbered 1, 2, 3 for left, center, right, respectively.

1. Pacing Options

The teacher may choose three options that govern how the device limits problem sessions. In the first option (the Timed option), the teacher limits the time the student works on a problem set. When the time runs out, the problem session ends. In the second option (Speed), the teacher is able to limit the amount of time per problem attempt, as well as the total number of problems. If the time per attempt runs out, the device acts as if the student had entered an incorrect answer; if the maximum number of problems have been reached the problem session ends. In the third option (Power) the limiting factor is the number of problems. The teacher limits the

TABLE I
ADDITION PROBLEM SETS

Problem Set Level	Range of Operands	
	Augend	Addend
1	0 to 4	0 to 4
2	0 to 4	5 to 9
3	5 to 9	0 to 4
4	5 to 9	5 to 9
5	0 to 9	0 to 9
6	0,10,20,...,90	0 to 9
7	0 to 9	0,10,20,...90
8	0,10,20,...90	0,10,20,...90
9*	10 to 99	0 to 9
10*	0 to 9	10 to 9
11	10 to 99	0 to 9
12	0 to 99	10 to 99
13*	19 to 99	10 to 99
14	10 to 99	10 to 99
15*	100 to 499	0 to 9
16*	0 to 9	100 to 499
17	100 to 499	0 to 9
18	0 to 9	100 to 499
19*	100 to 499	10 to 99
20*	10 to 99	100 to 499
21	100 to 499	10 to 99
22	10 to 99	100 to 499
23*	100 to 499	100 to 499
24	199 to 499	100 to 499
25	100 to 499	-499 to 499
26	-499 to 499	100 to 499
27	-499 to 499	-499 to 499

*NOTE: Indicates that problems containing regrouping are not members of the problem set.

TABLE II
SUBTRACTION PROBLEM SETS

Problem Set Level	R a n g e o f O p e r a n d s	
	Minuend	Subtrahend
1*	0 to 4	0 to 4
2*	0 to 4	5 to 9
3*	5 to 9	0 to 4
4*	5 to 9	5 to 9
5*	0 to 9	0 to 9
6**	10 to 99	10 to 99
7	0,10,20,...,90	0 to 9
8	10 to 99	0 to 9
9**	10 to 99	0 to 9
10**	100 to 499	0 to 9
11	100 to 499	0 to 9
12**	100 to 499	10 to 99
13	100 to 499	10 to 99
14**	100 to 499	100 to 499
15	0 to 9	0 to 9
16	19 to 99	10 to 99
17	100 to 499	100 to 499
18	0 to 9	-9 to 9
19	-9 to 9	0 to 9
20	-9 to 9	-9 to 9
21*	-499 to 499	-499 to 499

*NOTE: Indicates the given operand ranges are actually those of the augend and addend in the complementary addition problems.

**NOTE: Indicates that problems containing regrouping are not members of the problem set.

TABLE III
MULTIPLICATION AND DIVISION PROBLEM SETS

Problem Sets Level	Range of Operands *	
	Multiplicand	Multiplier
1	0 to 4	0 to 4
2	0 to 4	0 to 9
3	0 to 9	0 to 4
4	0 to 9	0 to 9
5	0,10,20,...,90	0 to 9
6	0 to 9	0,10,20,...,90
7	0 to 9	10 to 99
8	10 to 99	0 to 9
9	10 to 30	10 to 30
10	0 to 9	-9 to 9
11	-9 to 9	0 to 9
12	-30 to 30	-30 to 30

*NOTE: For division the problem is generated by the multiplication of numbers within the ranges in the table. The product is then placed in dividend position.

number of problems in the session, but the student may take any amount of time in responding to each problem. When the maximum number of problems have been completed the problem sessions ends.

2. Correct/Incorrect Answers and Repeat Key

Several standard phrases were created: When a problem has been answered correctly, a string of three low tones are said by the synthesizer; An incorrect response elicits two high tones. The words "go please", serve as a general purpose audio prompt.

The device also has the capability to repeat a problem set verbatim. The major use of this feature would be if the teacher noticed that the student had difficulty with the present problem set. The teacher could then cause the problem set to be repeated, and observe the types of problems that give the student the most difficulty.

If a sighted student forgets the current problem, that student can simply look at the problem again. A blind student listening to a verbal problem should have the same opportunity. For this reason a repeat problem presentation button has been incorporated into the device. Pushing the repeat button, while the trainer is waiting for the answer to a problem, causes the problem to be re-read.

3. Keypad and Keypad Drill

Because many students are familiar with the Speech Plus calculator, the device's keypad is designed with the numeric keys in the same configuration as the calculator. The only difference being the presence of an enter key and a minus key (for negative number entry).

The device also has a keypad training drill, which begins after the teacher has completed setting up the Math Trainer. This drill will ask the student to depress the keys on the keypad in order, saying "zero please", "one please", etc. If the student hits the correct key, that key will echo its designation and sound a tone. Wrong keys will only echo their designations. Pushing the repeat button will cause the keyboard drill to end and the problem session to begin.

D. Setting Up (Programming) the Trainer for Use

Before each problem session, the teacher will have to set up (Program) the device in the desired configuration. Parameters such as teaching mode, operation to be performed, location of missing number, number of problems, level of difficulty, etc. must be supplied to the device. Verbal asking of the required questions is not possible with the limited vocabulary of the device. Therefore, a scheme using a prompt beside a written statement (in both braille and print) of the parameter to be entered is used. The prompt is an illuminated LED next to a print and braille label. The following sequence of events takes place in setting up the device for student use:

- 1) Teacher turns device on.
- 2) Teacher chooses either Range or Level mode via R or L keys in PROB column.
- 3) The Pacing Option (Timed, Speed, Power) is selected via the PACE column.
- 4) If the Time Option was selected the teacher enters the total time limit (via the keypad) in minutes and seconds (up to 99 minutes

and 99 seconds) remembering to push ENTER after the last digit.

- 5) If the Speed Option was selected the teacher enters in the time limit per attempt in minutes and seconds (up to 20 minutes).
[Push ENTER].
- 6) If the Timed Option has not been selected the teacher enters the number of problems in the problem session via the keypad.
[Push ENTER].
- 7) The teacher keys in the operation (+, -, x, ÷).
- 8) If the Level Mode was selected the teacher keys in the level of difficulty number. [Push ENTER].
- 9) If the Range Mode was chosen the teacher enters the high and low limits of the first operand followed by the high and low limits of the second operand. [Push ENTER after each high or low limit].

The sequence of events that the student sees are shown below:

- 1) The trainer begins the keyboard drill. The student should press the zero key when the device says "Zero Please". The remainder of the keys are treated in a similar fashion. [NOTE: to skip the keyboard drill, push the REPEAT key.]
- 2) The trainer begins the problem session. In response to a problem, the student should enter his (or her) answer using the keypad, followed by pushing the ENTER key. Correct responses are followed by three low tones, after which the problem and answer are spoken. An incorrect response to the first presentation of a problem is followed by two high tones and a second, and final, presentation of that problem. A second incorrect response is followed by two high tones, after which the problem and answer are spoken.

Pushing a programming key causes the previous entries to be erased and the words "Go Please" to be said.

- 3) When the problem session is over the device reports the student's score and the total student response time. After the device says "STOP" the entire problem session can be repeated by pushing the Repeat button. Pushing the Restart button, at this or at any time, causes the trainer to start over at the point where the teacher chooses the Range or Level modes. Pushing any other key will cause the device to say the score again.

VITA

The author of this thesis, Michael Joseph Linnig, was born on May 23, 1956, in Louisville, Kentucky.

His elementary education was obtained at St. Clement's School and St. Timothy's School in Louisville. His secondary education was obtained at Bishop David High School, also in Louisville. He graduated from Bishop David in May, 1974.

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