COMPUTER-ASSISTED INSTRUCTION IN INITIAL READING

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COMPUTER-ASSISTED INSTRUCTION IN INITIAL READING*

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The Stanford computer-assisted instruction (CAI) program in initial reading has evolved during the last eight years through use with children in grades K through 3. When used with school classes for children who are below grade level in reading, this method of individualized instruction has produced significant and consistent gains in reading achievement over what would be expected from classroom instruction alone. In this report we outline the basic elements of the program and discuss individualized instruction based on optimization procedures. These procedures include optimal allocation of instructional time among methods of reading instruction and among students. We also discuss methods for determining how many times a student should study each curriculum item (word, phonetic spelling pattern, etc.). The optimization procedures have been reviewed by Atkinson and Paulson (1972), Chant and Atkinson (1973), and Atkinson (1968,1972a).

Initially, the aim of the project was to implement a complete CAI reading curriculum which would depend minimally on classroom activity. These early efforts were successful (Atkinson 1967a,b; 1968; 1969; Atkinson and Hansen, 1966), but it became clear that some aspects of reading instruction are better left to the classroom teacher. One of the aims of our research was to design, implement, and evaluate a low-cost CAI reading curriculum that would supplement normal classroom instruction.

CAI is important in teaching reading because it provides effective individualized instruction. Our interpretation of the literature on teaching children to read is that when instruction is not individualized, method variables account for a small percentage of the variance in reading achievement. Much of our work is aimed at making the teaching sequence sensitive on a moment-to-moment basis to the student's unique history of performance.

The reading program is now used at Brentwood Elementary School in East Palo Alto, which is located a few miles from Stanford University. The students receive CAI reading instruction for approximately 15 minutes every school day under the supervision of their teachers and a proctor. Instruction begins after the student types "R" for reading, an identification number, and his first name. The program responds with the student's last name and automatically transfers him to the point in the curriculum where he finished the last session. At the end of the instructional period, the program terminates the session by printing the words, letters, and phonetic elements the student has most recently learned.

The curriculum and instructional procedures do not demand complex terminals; each reading terminal consists of a "KSR Model 33" teletypewriter and earphones with an audio amplifier. There is no graphic or photographic capability at the terminal, and the character set of the teletypewriter includes only uppercase letters. The program is run on a PDP-10 computer operated at the Institute for Mathematical Studies in the Social Sciences (IMSSS) at Stanford University, and the terminals are connected to the IMSSS system by multiplexed telephone lines. The audio component of the reading program is versatile, and employs digitized representations of the vocabulary and commentary phrases stored on magnetic disk. Any one of 6,000 words and messages can be rapidly accessed.

The IMSSS computer system runs other curriculums, and serves users as far away as Washington, D.C., Florida, Oklahoma, and Texas. Approximately 3,000 students receive daily instruction in initial reading, arithmetic, logic, computer programming languages, language arts, foreign languages, and other curriculums on the system.

RATIONALE AND STRAND STRUCTURE

Learning to read can be divided into two basic tasks often referred to as decoding and communication. For our purposes, decoding is defined as the rapid, if not automatic, association of phonemes or phoneme groups with their respective graphic representations. Communication is defined as reading for meaning, aesthetic enjoyment, emphasis, and the like. The Stanford CAI reading program provides instruction in both types of skills but focuses primarily on decoding.

The reading program is divided into the following eight parts or strands:

Strand	Skill taught
0	Use of teletypewriter
I	Letter identification
II	Sight-word recognition
III	Spelling patterns
IV	Phonics
V	Spelling
VI	Word comprehension
VII	Sentence comprehension

Each strand, with the exception of Strand 0, has been designed to provide practice on a particular decoding or communication skill. In any session the student may study curriculum items from any or all strands; the amount of time spent in each strand is selected to maximize his progression through the curriculum. In other words, the instructional time is distributed optimally among the various forms of reading instruction. A description of the instructional process of each strand and a description of the procedure for allocating instructional time among the strands are presented later.

As shown in Figure 1, entry into a strand is determined by the student's level of achievement in the other strands. If the student has no CAI experience, his instruction begins in Strand 0 which teaches the skills required to interact with the program. Once strand 0 has been mastered, the student begins Strand I, which teaches the alphabet. When he has learned a subset of letters used in the earliest sight words of Strand II, he begins Strand II. Entry into the other strands is similarly defined but also involves maximum rate contours that are represented by the vertical dashed lines in Figure 1. Use of the contours is discussed later.

In each strand the student studies a curriculum item in two or three exercise formats; the most common formats

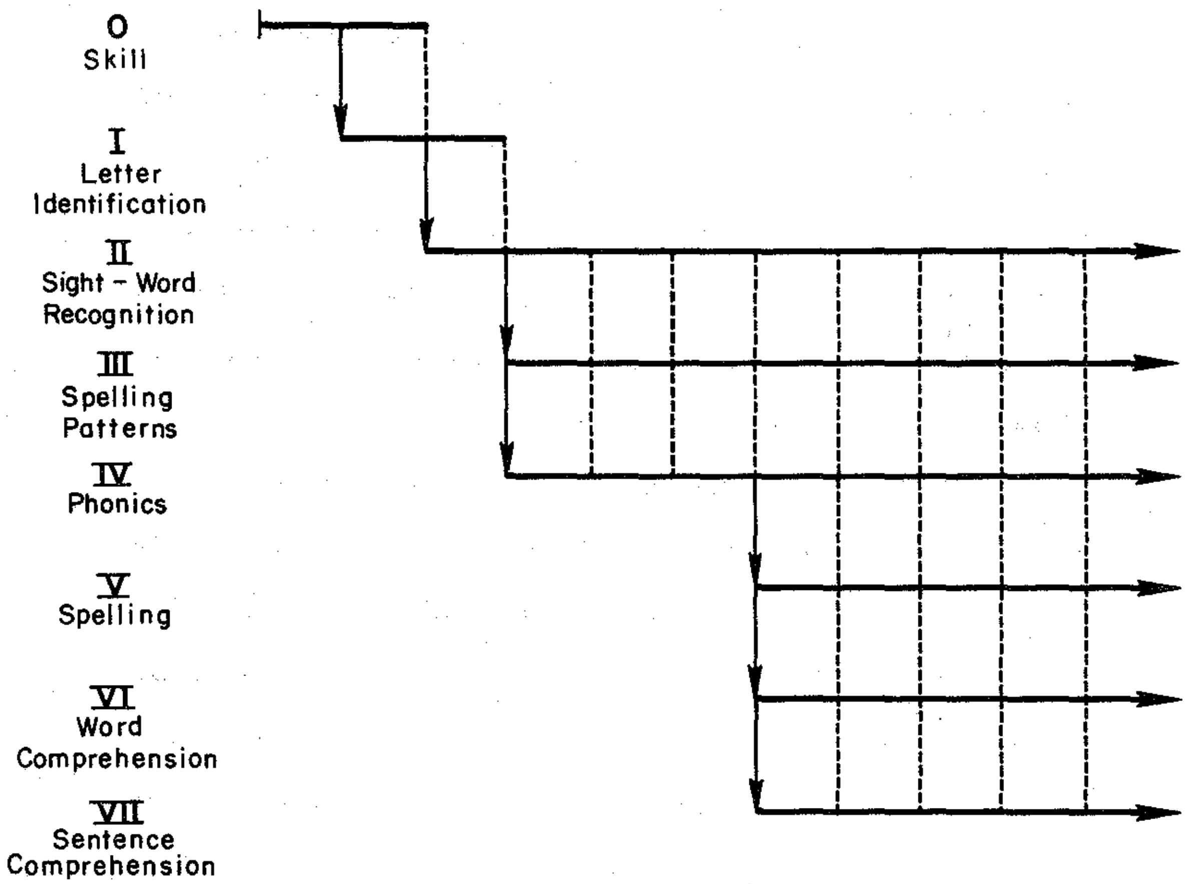

Figure 1. Initial entry points into strands. The vertical dotted lines represent maximal rate contours which control the student's progression in each strand relative to the other strands.

are copy, recognition, and recall. The instructional procedure varies from one exercise to the next, but in each a curriculum item is presented, a response (or response sequence) is elicited from the student, and feedback is given. For example, the recognition exercise in Strand III has the following format;

<u>Teletype Display</u>	<u>Audio Message</u>
BIKE LIKE STRIKE	Type STRIKE

Three words with similar spelling patterns are presented on the teletypewriter, followed by an audio presentation of one of the words. Control is then turned over to the student; if he types the correct response, a "+" is printed indicating to the student that he was correct; in addition the audio may give a reinforcing message such as "great" or "O.K." Whether or not there is to be a reinforcing audio message is decided probabilistically. If the student responds incorrectly or exceeds the allotted time, the program prints the correct word simultaneously with its audio presentation. Associated with each exercise is a performance criterion that must be met before the student branches to the next exercise.

Figure 2 illustrates the procedure in each strand for deciding which item the student is to study and in which

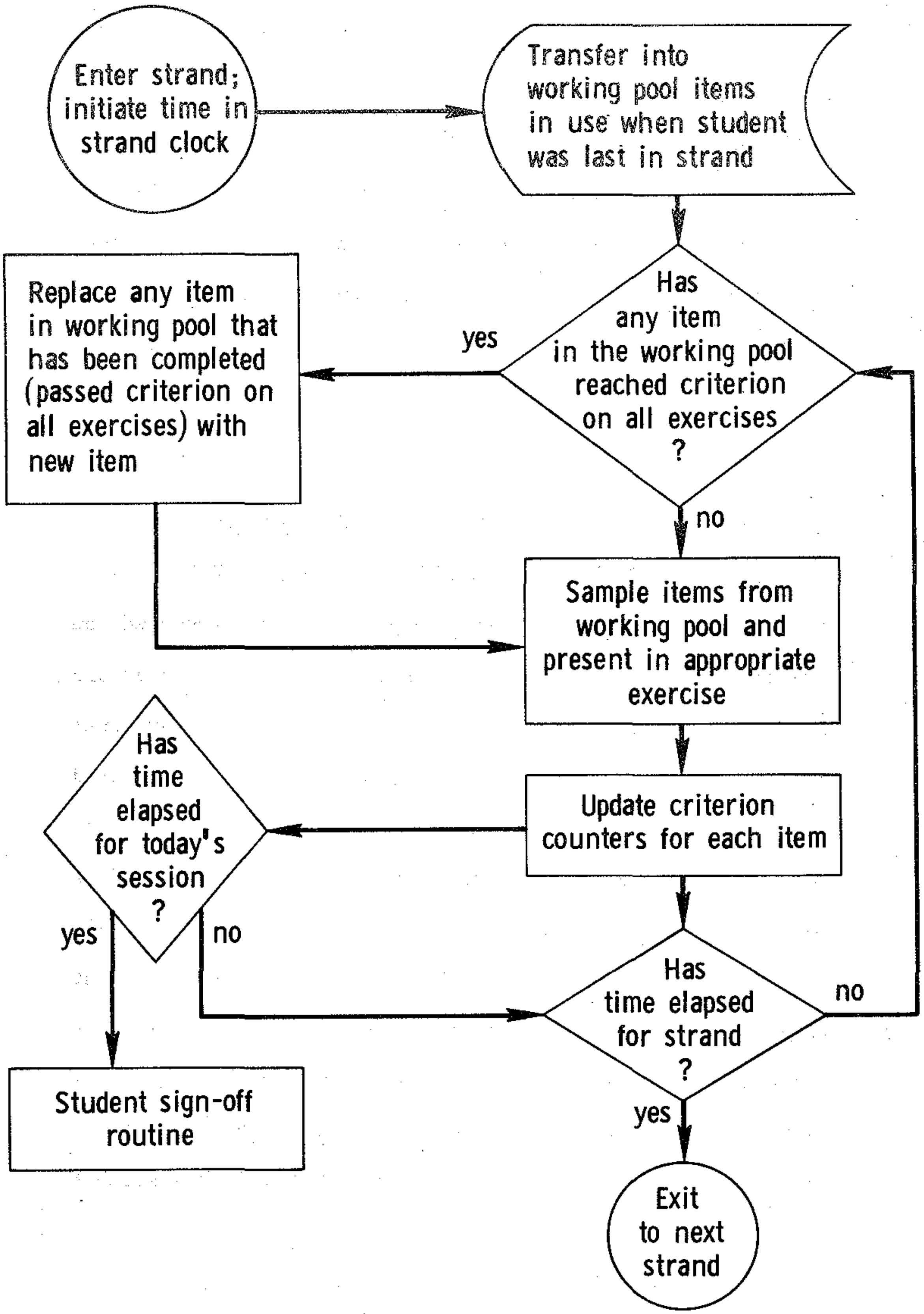

Figure 2. Flow diagram for presentation of curriculum items.

exercise format it will be presented. The process shown is common to all strands except that Strand II has additional provisions for review and pretest. The procedure is conceptualized as a flow process whose components are a a list of items, a working pool of items, and instructional exercises. Items used in a strand are listed in the curriculum and at any one time a small subset from the full list is selected to form a working pool for for the student's study. Generally six items are in the working pool, but this number varies somewhat from strand to strand.

The items the student is to study are sampled at random (without replacement) from the working pool and are presented to the student in one of the exercise formats. The sampling continues until each item in the working pool has been presented. When this occurs, a decision is made to shift the student to another strand, to sign the student off depending on how much time he has spent in the current CAI session, or to replace those items in the working pool which the student has completed (brought to criterion) and to continue in the current strand.

Each item in the working pool is considered to be in a particular instructional state that determines the exercise in which the item will be presented. The possible instructional states are designated as S_1, $S_2, \ldots, S_n$, corresponding to the 1st, 2nd,..., nth exercises. The first time an item is drawn from the working pool it is in state 1 and is presented in the format of the first exercise. When the student passes the first-exercise criterion for that item, its instructional state is updated to S_2. The next presentation of the item is in the format of the second exercise. When the student passes the last-exercise criterion for an item, it is completed and replaced in the working pool by a new item from the curriculum list. At any given time, the working pool will consist of items that are in various instructional states.

Strands II and IV have been emphasized in our recent research, and consequently will be described in considerable detail in the next two sections.

STRAND II: SIGHT WORD RECOGNITION

The objective of Strand II is to teach a sight-word vocabulary. The strand uses a vocabulary of 700 words presented in a sequence of increasing difficulty. The vocabulary list was selected and organized on the basis of a detailed analysis of several reading texts as well as sight-word lists (Atkinson and Fletcher, 1972).

The structure of Strand II, as shown in Figure 3,

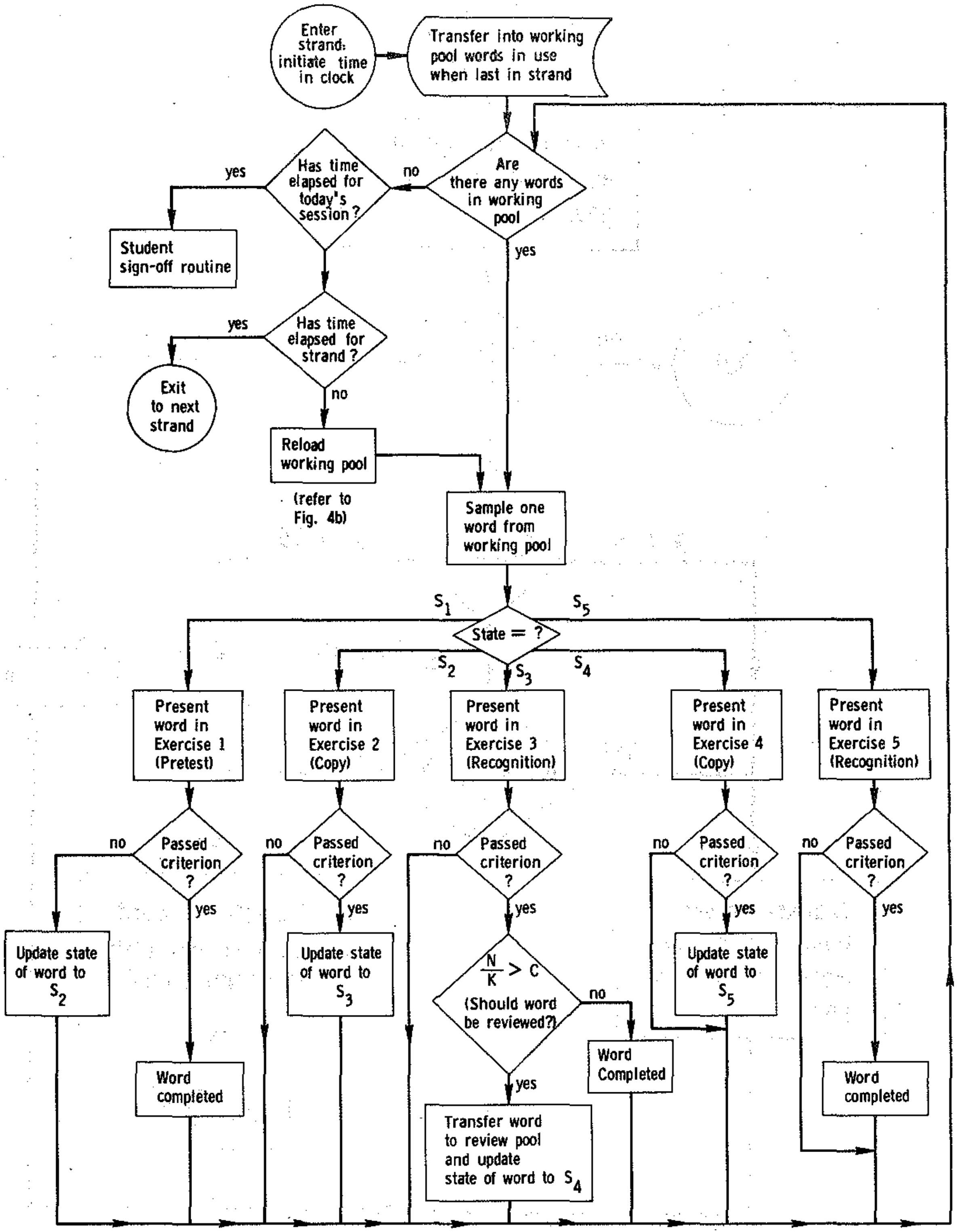

Figure 3a. Flow diagram for Strand II: Sight-word recognition.

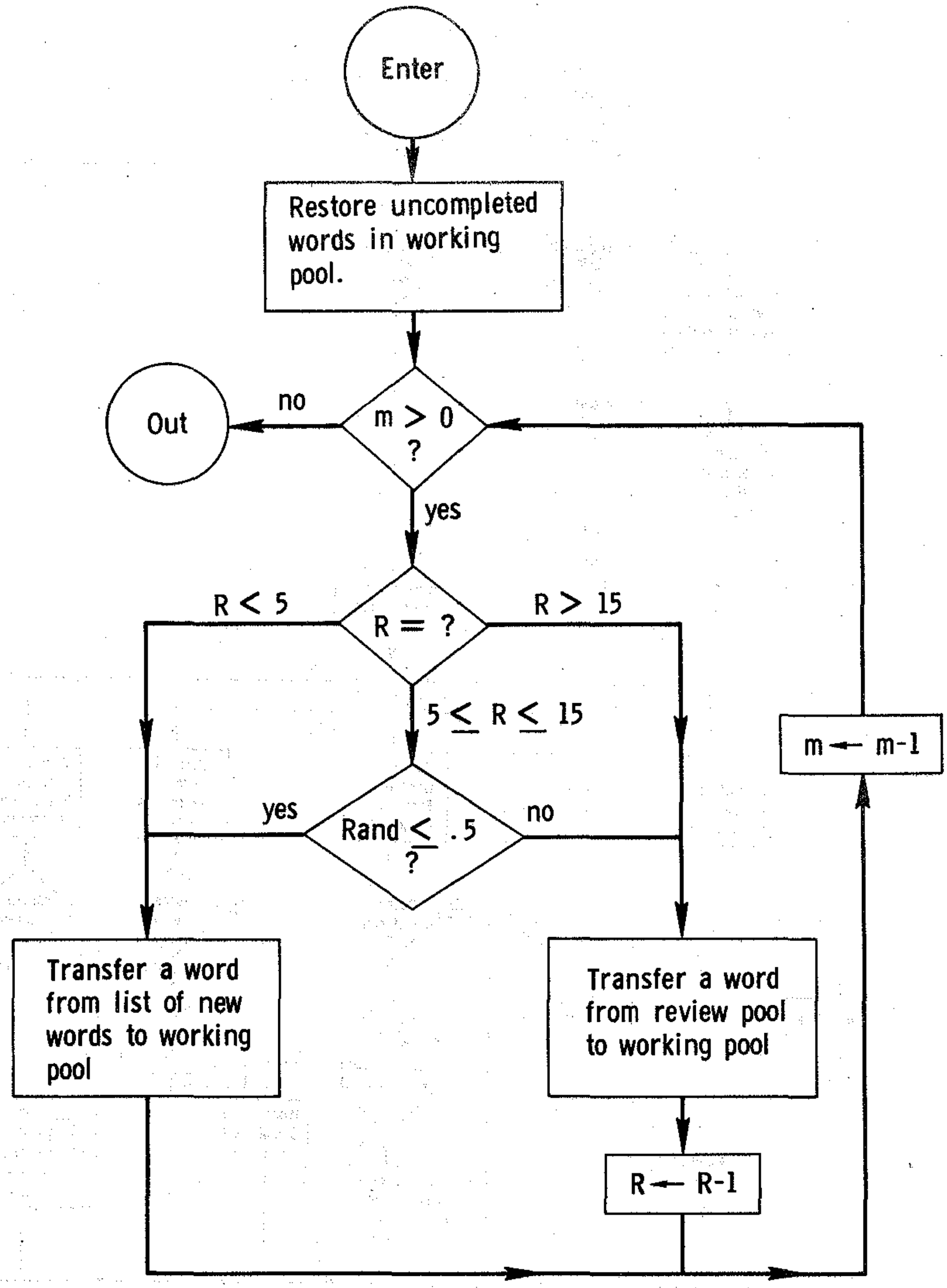

Figure 3b. Flow diagram for reloading words into working pool. R = number of words in review pool, M = number of words to be transferred into working pool from new list and review pool, and RAND = uniform random number between 0 and 1.

follows the flow process presented earlier with two additions: a pretest that allows students to skip words they already know, and a review option for words that require further study. Figure 3a illustrates how an item is sequenced through the five possible instructional formats; Figure 2b shows the procedure for replacing words the student has completed with words from either the curriculum list or review pool.

<u>Exercise Formats</u>

In Strand II there are five exercises each utilizing either the copy or recognition formats. Exercise 1 (the pretest) uses the recognition format. Exercises 2 and 3 (the main part of the strand) use the copy and recognition formats, respectively. If review is needed the student studies the word again in the copy and recognition formats with lower criteria. These review presentations are designated as Exercises 4 and 5. Examples of the exercises are shown in Figure 4. Note that when the student makes an error, the correct answer is then typed by the computer. In an earlier version of the program the student was required to copy the correct answer following an error; experimental work, however, demonstrated that this additional step did not facilitate learning (Atkinson, 1967b).

	Teletypewriter Display	Audio Message
The program outputs:	PEN	(Type pen.)
The student responds by typing:	PEN	
The program outputs:	+	(Great!)
The program outputs:	EGG	(Type egg.)
The student responds by typing:	EFF	
The program outputs:	////EGG	(No Egg.)

(a) COPY EXERCISE

	Teletypwriter Display	Audio Message
The program outputs:	PEN NET EGG	(Type pen.)
The student responds by typing:	PEN	
The program outputs:	+	
The program outputs:	NET PEN EGG	(Type net.)
The student responds by typing:	NET	
The program outputs:	+	(Fabulous !)

(b) RECOGNITION EXERCISE

Fig. 4 Strand II: Sight-word vocabulary exercises.

Flow of Words in Strand II

At any given time six words are in the working pool, each in one of five instructional states. The student is pretested (Exercise 1) on a word the first time it is sampled from the working pool in order to eliminate words already known. If he knows the word, he will pass criterion for the pretest and the word will be dropped from the working pool. If the student does not pass the pretest, he studies the word first in Exercise 2 and then in Exercise 3; if review is required he studies the word again in Exercises 4 and 5.

The review scheme provides a simple means of individualizing instruction with respect to the need to review a given item. The scheme is based on experimental evidence reported by Atkinson and Shiffrin (1968) and Atkinson (1972b). This evidence indicates that a word is more likely to be remembered if it is learned in relatively few attempts. As shown in Figure 3a, a word in state 3 is placed in the review pool with its state updated to S_4 if N/K is greater than C, The variable K is the criterion for Exercise 3 and N is the number of presentations the student required to reach criterion on Exercise 3; C is an arbitrary constant. By using the results of tests given periodically during the year, the effectiveness of the review scheme can be evaluated and C adjusted appropriately.

The student studies review words if the decision is made to transfer words from the review pool to the working pool. At present, if there are five words or fewer in the review pool, the next word to enter the working pool is sampled from the list of new words. If there are 15 words or more in the review pool, then the word is sampled from the review pool; if there are 5 or less the word is sampled from the curriculum list; otherwise, the word is sampled from either with probability 1/2. The first time a review word is sampled from the working pool it is in state 4, and the student studies the word in Exercise 4. When he passes criterion for Exercise 4, the state is updated to S_5. When the student passes criterion for exercise 5, the word is completed.

Individualizing Instruction in Strand II

In individualizing the flow of words in Strand II, the criterion for exercises other than the pretest depends upon student ability and the difficulty of a given word. The ability factor, α_i , of the ith student is defined as the proportion of wrong responses, over all the words on which the student has been pretested. This can be written as

$$\alpha_i = \frac{W'}{C' + W'}$$

where C' and W' are the number of correct and incorrect responses given on the pretest by the ith student (summed over all words he has seen). Similarly, the difficulty of the jth word in the curriculum, δ_j, is defined as

$$\delta_j = \frac{W''}{C'' + W''}$$

where C" and W" are the number correct and incorrect responses, respectively, to the jth word summed over all students who have ever run on the curriculum. The program automatically updates student ability and word difficulty factors on a daily basis.

The criterion of each exercise is defined in terms of student ability and word difficulty, so that a better student studies each word fewer times, and each student studies difficult words more times. In specifying the criterion Y_{ij} for student i on word j, the equation

$$Y_{ij} = A\alpha_i + D\delta_j + 1$$

is used. The parameters A and D are arbitrary constants that weight the importance of the ability and difficulty factors, respectively. Since the criterion must be an integer, Y_{ij} must be transformed. A simple transformation would be to take the nearest integer, in which case the criteria would increase in discrete steps as Y_{ij} increases. We chose instead to calculate the criterion probabilistically, thus letting the expected (average) value of the criterion increase linearly as Y_{ij} increases.

The objective of Strand II is to maximize the number of words completed over a given number of trials and at the same time maintain a high level of learning. Obviously the strand can be designed to allow almost every word to be completed in a minimal number of trials simply by decreasing the required criterion for each exercise. This procedure, however, does not maximize learning. On the other hand, if the criterion is set too high, then a word will continue to be presented after mastery, thereby using valuable time. Thus, one of the problems in maximizing the effectiveness of Strand II is to determine optimal values for the various criteria. If the criteria for the exercises are adjusted properly, there will be maximal flow of words through the strand for a predetermined level of learning.

STRAND IV: PHONICS

The objective of Strand IV is to help the student identify printed patterns of vowels and consonants that bear regular cor- respondences to phonemes. The strand uses a data base of four categories of spelling patterns, each of which is divided into sub- categories according to vowels. The student studies a specific spelling pattern of one vowel subcategory until he meets criterion and then is transferred to another subcategory.

Many phonics-oriented curriculums present spelling patterns only implicitly, that is within words, such as CAB, TAB, and SLAB. Moreover, many reading curriculums concentrate on final consonant spelling patterns, such as -AB, -AN, or -AT and exclude initial patterns such as CA-, TA-, and SLA-. Strand IV is unique in that it presents patterns not only embedded in words but also by themselves. Further, the strand presents initial consonant patterns as well as final consonant patterns.

Spelling Pattern Categories

The spelling patterns in the curriculum are grouped into the four categories -VC, CV-, -VVC, and CVV-, where V designates any vowel and C designates one or more consonants. The dash indicates that one or more consonants are needed to form a word and are supplied either by the student or by the program depending on the exercise. Each of the categories is divided into subcategories according to vowels. For example, category CV- consists of subcategories Ca-, Ce-, Ci-, Co-, and Cu-. Table 1 shows examples of words that incorporate the different spelling patterns. Note that category -VC also includes the spelling patterns -VCe̸, where e̸ denotes a silent e at the end of a word.

Exercise Formats

Strand IV provides the student with practice in three exercise formats; the student is required to recognize the spelling patterns themselves (Exercise 1), to recognize words that use them (Exercise 2), and to build a word from the spelling patterns (Exercise 3). In each exercise the student is presented with both audio and visual stimuli and is asked via audio to respond. The feedback procedure is the same as in other strands and is shown in Figure 5.

Branching Between Categories and Subcategories

The student studies spelling patterns from only one subcategory at a time. Each item is successively presented in the three exercise formats following the procedure illustrated in Figure 2. When the requisite number of items within a subcategory have passed the criterion for Exercise 3, a decision is made to determine which category and

Table 1

Examples of Spelling Patterns Used in Strand IV (Phonics)

Category	Subcategory	Examples		
-VC	-aC	RAN	MAN	VAN
	-iC	FISH	WISH	DISH
	-iC∅	QUITE	KITE	WHITE
CV-	Ci-	TRICK	TRIP	TRIM
	Ca-	DAD	DAMP	DASH
-VVC	-eaC	SEAT	MEAT	TREAT
	-ieC	LIED	FRIED	DIED
CVV-	Coo-	ROOF	ROOT	ROOM
	Cee-	FEET	FEEL	FEED

	Teletypewriter Display	Audio Message
The program outputs:	-IN -IT -IG	(Type /IG/ as in fig.)
The student responds by typing:	IG	
The program outputs:	+	(Good!)
The program outputs:	-IT -IN -IG	(Type /IT/ as in fit.)
The program responds by typing:	IT	
The program outputs:	+	
The program outputs:	-IG -IN -IT	(Type /IN/ as in pumpkin.)
The student responds by typing:	IN	
The program outputs:	+	(Fabulous!)

(a) RECOGNITION OF PHONETIC SPELLING PATTERNS

Fig. 5a: Strand IV: Phonics exercises.

(continued)

	Teletypewriter Display	Audio Message
The program outputs:	-IN -IT -IG	
	P--	(Type pin.)
The student responds by typing:	PIN	
The program outputs:	+	(Great!)
The program outputs:	-IG -IN -IT	
	F--	(Type fig.)
The student responds by typing:	FIN	
The program outputs:	///FIG	(No, we wanted fig.)
The program outputs:	-IN -IG -IT	
	SL--	(Type slit.)
The student responds by typing:	SLIT	
The program outputs:	+	(Good!)

(b) BUILD A WORD

Fig. 5b. Strand IV: Phonics exercises.

subcategory the student will study next.

The student begins in category -VC, and when the criterion is met, he is transferred to one of the categories CV-, -VVC, or CVV- with probability p_2, p_3, or p_4, respectively, or is retained in category -VC with probability p_1. This procedure is illustrated in Figure 6. As the figure shows, the student always transfers back to category -VC when he finishes one of the other categories.

Branching between vowel subcategories within each category occurs in a round robin fashion. Suppose the student has met the criterion for subcategories -aC and -eC within category -VC. When he returns to category -VC, after studying other categories, he enters at subcategory -iC. The branching scheme as illustrated in Figure 6 emphasizes the -VC category. At present, $p_1 = 1/2$, which means the student studies items in the -VC category for 2/3 of the total instructional time allocated to Strand IV. This emphasis reflects the results of a study by Fletcher (1973) in which practice with final consonant spelling patterns (-VC) was shown to produce better performance than practice with initial consonant spelling patterns (CV-).

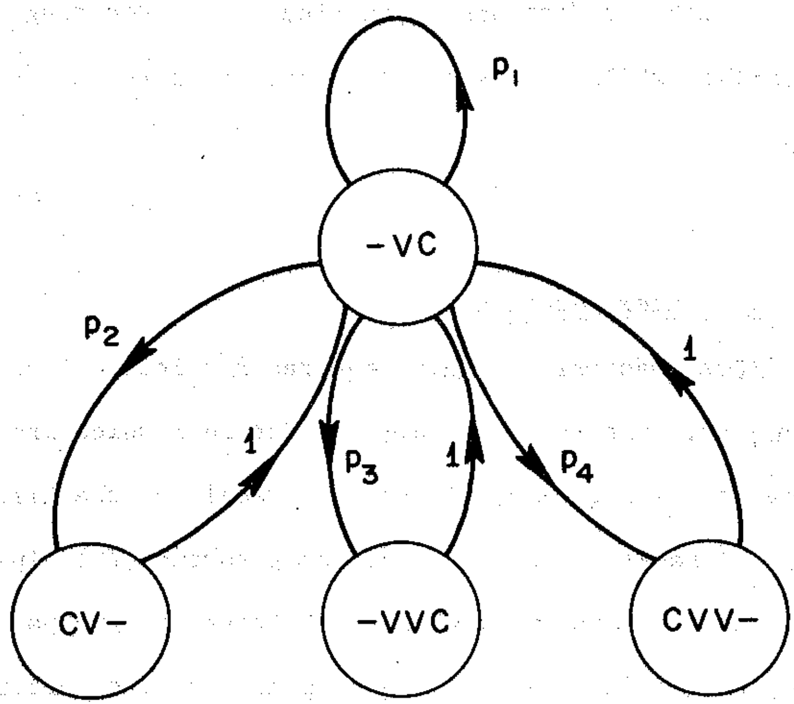

Fig. 6. Branching between vowel subcategories in Strand IV.

OTHER STRANDS

The other strands in the reading program provide the student with additional practice on decoding and communication skills. A brief explanation of these strands follows.

Strand I: Letter Recognition

After mastering skills required for interaction with the program, the student begins Strand I which provides practice in copying, recognition, and recall of the letters in the alphabet. The initial pass through the alphabet presents the letters in maximally contrasting groups (for example, RTO); the second pass presents the letters in minimally contrasting groups (for example, MNW).

Strand III: Spelling Patterns

Strand III provides practice with English spelling patterns and emphasizes regular grapheme-phoneme correspondences that occur in English. The strand flow structure is very similar to that shown in Figure 2 and uses recognition and recall exercises. Figure 7 illustrates the exercises used in Strand III. The curriculum items are

	Teletypewriter Display	Audio Message
The program outputs:	FAINT SAINT PAINT	(Type Saint.)
The student responds by typing:	FAINT	(No. Saint)
The program outputs:	TREAT MEAT SEAT	(Type seat.)
The student responds by typing:	SEAT	(Great!)

(a) RECOGNITION EXERCISE

Fig. 7a. Strand III: Spelling pattern exercises.

	Teletypewriter Display	Audio Message
The program outputs:		(Type tag.)
The student responds by typing:	TAG	
The program outputs:	+	(Good!) (Type flag.)
The student responds by typing:	FLAP	
The program outputs:	///FLAG	(No. Flag)

(b) RECALL EXERCISE

Fig. 7b. Strand III: Spelling pattern exercises.

monosyllabic words grouped in sets of three that emphasize a single spelling pattern such as MUST, CRUST, and TRUST.

Strand V: Spelling

In this strand the student is required to spell a word without seeing it, but the study procedure differs from the recall exercise in Strand III; if the student spells the word correctly the first time, the word is completed. If he spells it incorrectly the word is presented successivly in the copy exercise format until he copies it correctly at which point it is returned to the working pool. When the word is presented again, the student will be required to spell it without seeing it. The vocabulary consists primarily of short orthographically regular words that the student has already completed in Strands II and III.

Strand VI: Comprehension of Words

Strand VI emphasizes a word's semantic category. The student is asked to select the one word of those displayed that is a member of a given semantic category such as an animal, a color, or a person. Twenty two categories are used by the strand, allowing a fairly large vocabulary. The single exercise format used in Strand VI is illustrated in Figure 8.

Strand VII: Comprehension of Sentences

In this strand the student is required to complete a

	Teletypewriter Display	Audio Message
The program outputs:	HOUSE CAT GREEN	(Type the word that is an animal.)
The student responds by typing:	CAT	
The program outputs	+	(Fabulous!)
	THROAT APPLE YELLOW	(Type the word that is something to eat.)
The student responds by typing:	YELLOW	
The program outputs:	///APPLE	(No. An apple is something to eat.)

Fig. 8. Exercise in Strand VI: Word comprehension.

sentence by selecting one of three words, two that are distractors, and one that correctly completes the sentence. One distractor is either semantically or syntactically incorrect, and the other is unacceptable both semantically and syntactically. The single exercise format used in Strand VII is illustrated in Figure 9.

ALLOCATION OF INSTRUCTIONAL TIME AMONG STRANDS

The student progresses through the strands as shown in Figure 2. The dotted vertical lines represent maximal rate contours that control the student's progress in each strand relative to his progress in the other strands. The assumption that underlies use of the contours is that learning particular items in one strand facilitates learning particular items in another strand; thus the contours are constructed so that the student learns specific items from one strand in conjunction with specific items from other strands. For example, consider a student who is studying Strands II, III, and IV, and where the contours are defined so that he is expected to have learned 80 words, 15 spelling patterns, and 10 phonic items by the time he reaches contour 5. Suppose, however, that the student learns the 10 phonic

	Teletypewriter Display	Audio Message
The program outputs:	MAD DRIVE SWIM TIM WILL _ _ _ THE CAR.	(Type the word that completes the sentence.)
The student responds by typing:	DRIVE	
The program outputs:	+	(Great!)
The program outputs:	THE RAIN STORM LEFT _ _ _ . PUDDLES ZOO SURPRISED	(Type the word that completes the sentence.)
The student responds by typing:	PUDDLS	
The program outputs:	///PUDDLES	(No. Puddles)

Fig. 9. Exercises in Strand VII: Comprehension of sentences.

items before he learns the 80 words and 15 spelling patterns. In this case, the student's total time in the next instructional session is divided between Strands II and III, and the strand farthest from contour 5 receives the most time. In general, a student receives an amount of time in each strand proportional to the number of items yet to be completed in that strand before he reaches the next contour. Chant and Atkinson (1973) discussed in more detail the allocation of instructional time among interdependent strands and provided a theoretical rationale for use of maximal rate contours.

ALLOCATION OF INSTRUCTIONAL TIME AMONG STUDENTS

The effectiveness of the CAI program can also be increased by optimally allocating instructional time among students. Suppose that a school has budgeted a fixed amount of time T for CAI during the school year and must decide how to allocate the time among a class of k students. Let t_i be the time that is allocated to student i. Then the optimization problem is to find the values of $t_1, \ldots, t_k$ that will maximize the effectiveness of the CAI program.

Atkinson (1972a) has formulated a model that predicts performance on a standardized test in initial reading as a function of the amount of time the student spends on the CAI system. Specifically, let $P_i(t)$ be student i's performance on a standardized reading test administered at the end of the school year, given that the student spends time t on the CAI system during the year. Then, within certain limits, the following equation holds:

$$P_i(t) = \alpha_i - \beta_i \exp(-\gamma_i t) .$$

The parameters α_i, β_i, and γ_i characterize a given student and vary from one student to the next; α_i and $(\alpha_i - \beta_i)$ are measures of the student's maximal and minimal levels of achievement, respectively, and γ_i is a rate of progress measure. These parameters are estimated from the student's CAI response protocol obtained during the first hour of instruction.

If we are interested in maximizing the mean value of P over the class of students, the mathematical formulation required is:

maximize

$$\phi(t_1, t_2, \ldots, t_k) = \frac{1}{k} \sum_{i=1}^{k} P_i(t)$$

subject to the constraint

$$\sum_{i=1}^{k} t_i = T$$

and

$$t_i \geq 0 .$$

This maximization can be achieved by dynamic programming techniques, and the results of such an analysis are reported by Atkinson (1972a). Other optimization problems, such as minimizing the variance for the class of students, are easily solved by using the appropriate formulation of the objective function $\phi(t_1, t_2, \ldots, t_k)$.

MOTIVATION FEEDBACK AND TEACHING REPORTS

If an instructional strategy is effective, the student's progress should be sufficient reward. From this viewpoint, motivation becomes primarily a matter of showing the student his own progress and letting him know that progress is valued. To this end, the reading program incorporates four feedback procedures: (a) A student's correct answer is always acknowledged by printing "+." (b) Occasionally the student receives a word of audio acknowledgement like "groovy" or "great." (c) The student is told how he is doing during each session. When an item meets criterion, the audio says, "Another star," and a star is printed beside the word. Then the program prints, for example, "Lynn, you have passed ROUGH," together with a star for each item passed during that session. (d) The last six items completed in the sight-word, spelling patterns, and phonics strands are printed at the end of each session to provide review and further feedback.

The list of completed items may be taken home by the students, or it may be used by teachers for further review. Together with daily class reports, this information allows the teacher and proctor to pinpoint the items each student is studying.

The class reports contain for each student the number of minutes accumulated, the number of the curriculum items completed in each strand, and a (+) if the student was on the program that day. An example of a daily class report is shown in Figure 10.

EFFECTIVENESS AND COST

The CAI reading program has been used in several elementary schools, and incorporates the experience gained through eight years of continued use. The reading program combines elements of research with instruction and has been adapted to the day-to-day needs of public schools by using simple and reliable equipment.

While several evaluative studies of the program have been conducted, one which used a control group will be reviewed here. Fletcher and Atkinson (1972) matched 50

CLASS 17 MRS. L. MCNANY 12 MAR 73
28 STUDENTS -- BRENTWOOD ELEMENTARY SCHOOL -- GRADE 2

READING REPORT -- TYPES + IF RUN TODAY

MIN		L	W	SP	PH	CC	CS		
505.4		52	129	34	16	8	1	3083	TERRY BAKER
405.3		54	157	70	67	19	19	3084	MELVIN HALL
706.7		52	180	79	73	9	18	3087	CALVIN DUNN
673.7		52	412	112	137	18	35	3089	MAURICE CALDWELL
698.4		52	496	100	117	16	34	3168	SABRINA EAST
735.1		52	404	103	120	18	32	3173	TROY JACKSON
557.2		52	172	70	53	10	14	3186	CORNELL WATSON
513.2		52	177	79	68	20	21	3220	DARRIN BANKS
750.7		55	321	142	189	17	52	3222	SOPHIE BOBAN
652.3		52	234	82	76	16	22	3223	ANTHONY CANNON
611.5		55	517	142	185	23	50	3224	DEMETRIOS COLE
656.7		52	465	91	98	17	27	3225	DAVID CROSBY
548.0		52	303	88	88	18	25	3226	CULLIN GUILLORY
649.6		52	386	112	126	24	36	3227	CHAUNCEY FERGUSON
534.4		52	319	94	94	19	28	3228	CEACY GRIFFIN
461.7		52	327	91	86	14	27	3229	WILLIE GRIFFIN
374.9		52	343	61	39	11	13	3230	JULIET HARRIS
524.4		52	247	109	132	25	35	3231	KIMBERLY HARRISON
479.5		52	195	91	97	26	25	3232	CLAUDIA JORDAN
565.6		52	279	73	62	12	17	3233	LONNIE LEE
352.1		52	48	13	7	1	1	3234	JOSEPH MANAGO
552.0		55	378	100	120	17	36	3235	TRACY METOYER
617.7		52	85	34	10	7	1	3236	WINSTON PARKER
459.5		52	323	82	77	19	28	3237	FELICIA POUNDS
289.8		52	24	16	7	1	1	3240	CURTIS THOMPSON
510.0		52	117	31	10	1	1	3241	LYNITA WALKER
695.5		55	353	127	160	24	45	3242	MONIQUE WILTZ
335.9		52	255	58	34	9	10	3272	BILLY MCHOLDER
AVERAGES									
550.6	0	52	273	81	83	14	23		
MINIMUMS									
289.8	0	52	24	13	7	1	1		
MAXIMUMS									
750.7	0	55	517	142	189	26	52		

Fig. 10. Daily class report.

pairs of first grade students on a number of variables, including reading readiness scores. One member of each pair received CAI in initial reading, and the other member did not. Students who participated in this experiment received CAI for only a 5-month period during the first grade and received no CAI during the second grade. The CAI lasted for approximately 12 minutes per day; except for this twelve-minute period, the school day for the CAI group was like that of the control group. Standardized tests were administered at the end of the first grade and again at the end of the second grade. The testing was done by a team who were unaware of the experimental treatments. The end-of-year results indicated that the CAI group achieved a 5.05 month gain in performance over the control group. The groups, when tested a year later with no intervening CAI treatment, showed a difference of 4.90 months in favor of the original CAI group. The CAI effect apparently persisted for a year after the CAI was administered. In interpreting these results it should be borne in mind that these first grade CAI students received only a total of about 20 hours of on-line instruction.

Moreover, the results indicated that boys on the average benefited more than girls. On all reading tests used in the evaluation, the girls as a group were superior to the boys; however, for the control group the magnitude of the difference between boys and girls was greater than for the experimental group, which suggests that both boys and girls benefit from CAI instruction, but that it is relatively more effective for boys. This finding replicates an earlier result reported by Atkinson (1968) who presented a discussion of why males might be expected to show a larger gain than females when CAI is used.

Costs per student session of CAI have decreased with the use of inexpensive equipment and with the general decrease in computer hardware costs. The audio component of the system entails the greatest costs, but technological developments may significantly decrease these costs in the near future. For conventional education of the same quality provided by CAI, Kiesling (1972) estimated the cost in urban and suburban areas at $200 to 300 in addition to the normal school allotment for that student. The CAI reading program using the present system can be made available to students for a yearly cost below $200. For a discussion of this point see Jamison, Fletcher, Suppes, and Atkinson (1973).

CONCLUDING COMMENTS

The CAI program described here is intended as a tool to be used in conjunction with other forms of instruction. No extensive teacher training is required for its use; in fact, experience indicates that teachers have little difficulty familiarizing themselves with the basic features of the program and in using the computer printouts.

It should be emphasized that the program is experimental; each day we learn something new. Discussions with teachers and students, as well as analyses of student-response histories, permit us to devise better procedures for individualizing exercises, for branching among strands, and for distributing review.

REFERENCES

Atkinson, R. C. Instruction in initial reading under computer control: The Stanford project. *Journal of Educational Data Processing*, 1967, *4*, 175-192. (a)

Atkinson, R. C. Learning aspects of computer-assisted instruction. In R. W. Gerard (Ed.), *Computers and education*. New York: McGraw-Hill, 1967. (b)

Atkinson, R. C. Computerized instruction and the learning process. *American Psychologist*, 1968, *23*, 225-39.

Atkinson, R. C. Computer-assisted learning in action. *Proceedings of the National Academy of Sciences*, 1969, *63*, 688-94.

Atkinson, R. C. Ingredients for a theory of instruction. *American Psychologist*, 1972, *27*, 921-931. (a)

Atkinson, R. C. Optimizing the learning of a second-language vocabulary. *Journal of Experimental Psychology*, 1972, *96*, 124-129. (b)

Atkinson, R. C., and Fletcher, J. D. Teaching children to read with a computer. *The Reading Teacher*, 1972, 319-327.

Atkinson, R. C., and Hansen, D. N. Computer-assisted instruction in initial reading: The Stanford project. *Reading Research Quarterly*, 1966, *2*, 5-25.

Atkinson, R. C., and Paulson, J. A. An approach to the psychology of instruction. *Psychological Bulletin*, 1972, *78*, 49-61.

Atkinson, R. C., and Shiffrin, R. M. Human memory: A proposed system and its control processes. In K. W. Spence and J. T. Spence (Eds.), *The Psychology of learning and motivation: Advances in research and theory*, Vol. 2. New York: Academic Press, 1968.

Chant, V. G., and Atkinson, R. C. Optimal allocation of instructional effort to interrelated learning strands. *Journal of Mathematical Psychology*, 1973, *10*, 1-25.

Fletcher, J. D. Transfer from initial unit and final unit spelling patterns presented in initial reading. Unpublished doctoral dissertation, Stanford University, 1973.

Fletcher, J. D., and Atkinson, R. C. An evaluation of the Stanford CAI program in initial reading. *Journal of Educational Psychology*, 1972, *63*, 597-602.

Jamison, D., Fletcher, J. D., Suppes, P., and Atkinson, R. C. Cost and performance of computer-assisted instruction for education of disadvantaged children. In J. Froomkin and R. Radner (Eds.), *Education as an Industry*, *National Bureau of Economic Research*, Columbia University Press, 1973.

Kiesling, H. J. *Input and output in California compensatory education projects.* (R-781-CC/RL) Santa Monica, California: Rand Corp., 1972.

FOOTNOTE

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