COMPUTER-ASSISTED INSTRUCTION IN INITIAL READING:

THE STANFORD PROJECT

by

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COMPUTER-ASSISTED INSTRUCTION IN INITIAL READING: THE STANFORD PROJECT*

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The purpose of this paper is to describe a computer-based system and curriculum for teaching initial reading completely under computer control. The system and curriculum are organized so that instruction is on an individual basis with each child progressing at his own pace through a subset of materials designed to be best-suited to his particular aptitudes and abilities.

From our viewpoint there are several major reasons for developing a computer-based system for instruction in initial reading. The immediate and most obvious one is to establish the feasibility of this mode of instruction with young children. There are a number of studies in the literature on programmed instruction and some of our own research, to be described later, which indicate that computer-based reading programs can be highly effective for short periods of time. However, there have been no studies in which children have received all or a large part of their reading instruction under computer control for significantly long periods of time. Evaluation over an extended period of time is necessary, and we

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plan to conduct such a study starting in September of 1966. Approximately 100 first-grade children will be involved for a minimum period of one school year and will receive the major portion of their reading instruction under computer control.

In addition to determining the long-run feasibility of this approach we also see the computer system as providing a school-based laboratory in which to conduct curriculum research and evaluation. In this laboratory it will be possible to run curriculum experiments under conditions where the instructional materials can be specified precisely, and at the same time to obtain a detailed record of each student's performance. In the past it has not been possible to conduct curriculum studies under controlled experimental conditions and consequently in almost every study there have been extraneous variables, the effects of which could not be assessed. The presence of these variables has left most interpretations of the results open to serious question.

An equally important criticism of most curriculum studies is that the response information collected is seriously limited. The data that is collected is usually obtained under test conditions, and generally fails to provide critical information regarding the nature of the difficulty the child is experiencing with particular aspects of the curriculum. With the computer system it is possible to run curriculum studies under controlled experimental conditions and at the same time keep a running record of each child's performance.

Of course, the computer system offers the learning theorist the same advantages as it does to the curriculum expert. In the past, psychologists interested in human learning have not shown a great deal of enthusiasm for studying the acquisition and retention processes involved in mastering a subject-matter area such as initial reading or mathematics. Instead they have preferred to study the college student as he learns highly contrived and artificial materials. The reason is not that the learning theorist is disinterested in more complex phenomena, but rather he feels that he cannot exercise sufficient experimental controls to gain accurate and meaningful data. With the computer system this objection is no longer warranted, for now we can study subject-matter learning under conditions of greater control and with more precision in response-recording than has ever been possible before even in the psychologist's laboratory.

It is our hope that a computer-based laboratory of the type to be described in this report will make it possible to obtain rigorous behavioral measures on curriculum innovations and developments. At the same time we will be able to carry out long-term learning studies under precise experimental control, and with the capability of collecting detailed response data. Thus the computer-based laboratory should have a direct effect on curriculum efforts, and also on the type and scope of experimentation undertaken by learning theorists. Development of these two avenues of research should have significant consequences for their respective fields, but they should also provide the basis for developing a viable "theory of instruction," that is, a theory that will prescribe the conditions under which an instructional procedure optimizes learning. If we have a good understanding of the special features of a given curriculum and have a reasonably accurate theory of learning, then taken together they will imply a set of decision rules that specify the most effective way of sequencing the student through the instructional materials.

The Stanford Computer-Assisted Instructional (CAI) System

The Stanford CAI System is designed to present instructional materials to 16 students simultaneously, with the possibility that each student may be working on a completely different set of materials. The reading curriculum to be described later is organized so that each child can progress at his own pace branching along a pathway of materials that reflects his particular competencies. It is to be emphasized that every aspect of the instructional sequence is specified beforehand in minute detail. Every visual display and auditory message that the student may receive--a reply to every response he may conceivably give--a decision procedure for utilizing past performance to determine materials to be presented next--a coding scheme for storing information on the student's data record--must all be planned and prepared in advance. Further, when an instructional session is finished we have a complete record of the sequence of materials presented to the child and his history of responses.

The Stanford system consists of a central process computer (IBM 1800) and accompanying tape-storage units, disc-storage units, card reader/punch, line printer, two proctor stations, and an interphase to 16 student terminals. The central process computer acts as an intermediary between each student and his particular course material which is stored in one of the disc-storage units. A student terminal consists of the following devices: 1) a picture projector, 2) a cathode ray tube--CRT, 3) a light-pen associated with the CRT, 4) a modified typewriter keyboard, and 5) an audio system which can play pre-recorded messages.

Visual material may be presented to the child on both the CRT and on the film projector. The CRT can display alphabetic or numeric symbols on a 7" × 9" screen with 16 lines and 40 spaces per line. A limited dictionary of specific line drawings (pictorial patterns) may also be displayed on the CRT. Provision has been made for superscript and subscript positioning of all characters. To gain the attention of the student, an emphasis indicator can be positioned at any point on the CRT screen to highlight selected items. The indicator may also move along the screen in synchronism with an audio message to emphasize given words, phrases, etc., much like the "bouncing ball" in a singing cartoon.

The pictorial projector is a random-access 16 mm. film device that presents a still image on a 7" × 9" screen. The projected image may be in color or in black and white. The film images are stored in a cartridge with a capacity of 1024 pictures, any one of which can be selected randomly. The time required to change a film cartridge is less than one minute.

The student receives audio messages via a random-access control device capable of selecting any message which may vary in length from one second up to 15 minutes. The audio messages are stored in tape cartridges

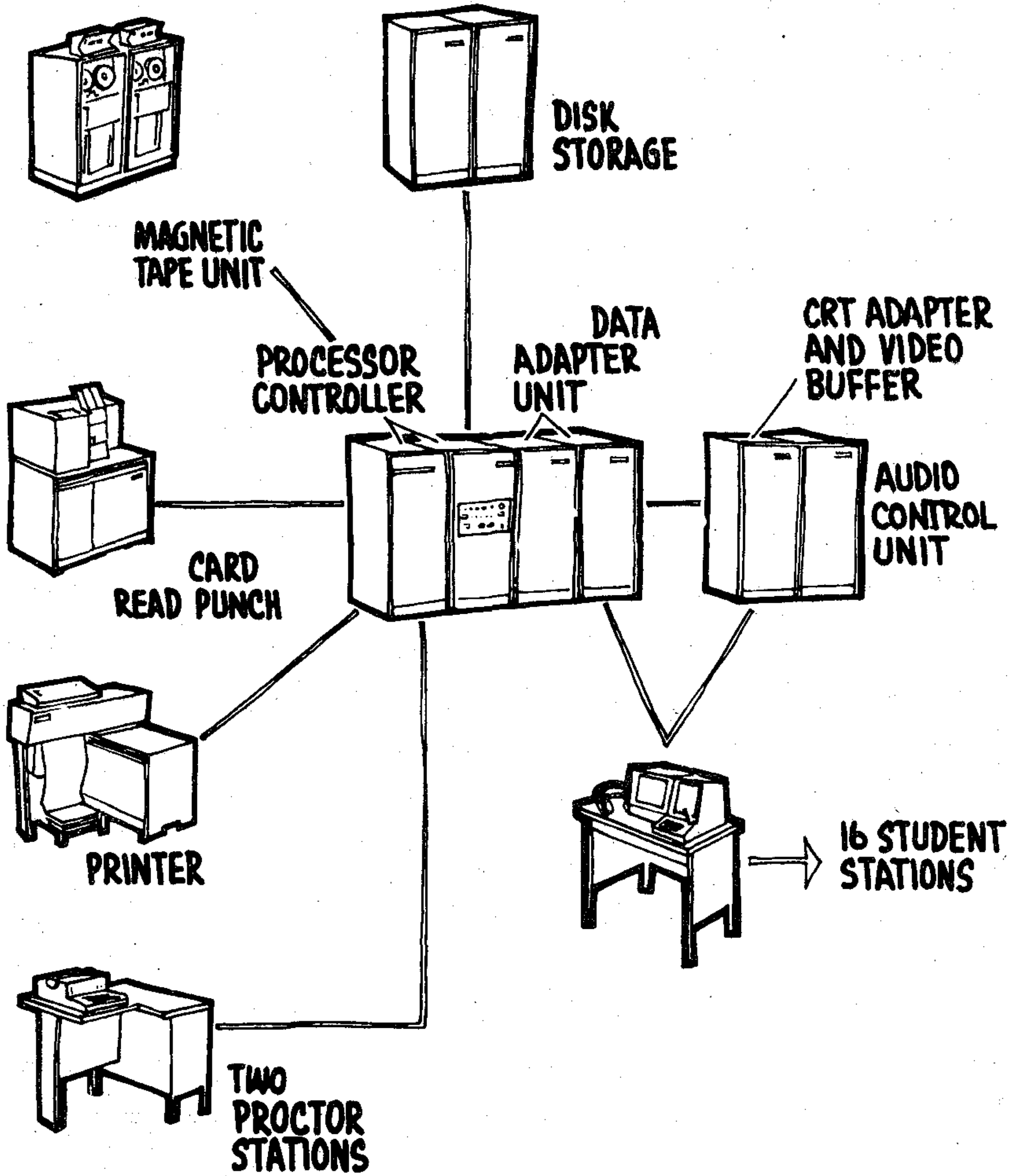

Figure 1. System Configuration for Computer-Assisted Instruction

which contain approximately three hours of audio, and like the film cartridge, may be changed very quickly.

The child can respond to the auditory and visual displays via three input modes: a hand-held light-pen, a typewriter keyset, or a microphone recorder. The student uses the light-pen by touching any point on the CRT screen. While the student is positioning the pen, an automatically generated brightening of the area on the display aids him in determining the exact location of the end of the light-pen. Coordinates of the location touched by the light-pen are sensed as a response and recorded by the computer. Each student terminal is also equipped with a keyboard. When the computer activates the keyboard, the student may enter his responses by striking the desired keys and (depending on the problem) may or may not see the characters displayed on the CRT. If desired, a cursor can be used to indicate to the child where on the screen the next character will be displayed. The third input mode allows the student to use a microphone to make voice recordings that are stored on the audio tape and can be played back at any later time as determined by the particular instructional program. These student recordings may be saved for off-line analysis.

When the sequence of instructional events requires a student response, a ready light comes on to indicate to the student that the system expects and is prepared for a response entry. The light is turned off when a response has been completed.

The system controls the flow of information and the input of student responses according to the instructional logic built into the curriculum materials. The sequence of events is roughly as follows: the computer pulls in from a disc-storage unit the necessary commands for a given instructional sequence or problem. These commands involve directions to the terminal devices to display a sequence of alpha-numeric symbols and specified pictorial symbols on the CRT, to present a given image on the projector, and to play a particular audio message. After the appropriate visual and auditory material has been presented, a ready light comes on to tell the student to respond. Once a response has been entered it is evaluated by the computer and (on the basis of this evaluation and the student's past history) makes a decision as to what material is to be presented next. The time-sharing nature of the system allows for a cycle through these evaluation steps in less than one or two seconds.

As each response is input to the system, it is recorded in a canonical form that identifies the student, the particular problem he is working on, the response made, and the response latency. Thus, a complete history is available on each student which can be used on-line to make decisions regarding the instructional sequence, and off-line for research purposes.

Lesson Preparation and Data Recording

There are a number of special problems that arise in the computer programming required to present a reading lesson. To give the reader some feeling for these problems we now consider a simple example in some detail. The example is from one of our lessons designed to teach the beginning reader both letter discrimination and the meaning of words. A picture illustrating the word being taught is presented on the projector screen. Three words, including the word illustrated, are presented on the CRT screen. A message is played on the audio asking the child to touch the word on the CRT that matches the picture on the film projector. The student can then make his response using the light-pen. If he makes no response within the specified time limit of 30 seconds, he is told the correct answer, an arrow points to it, and he is asked to touch it. If he makes a response within the time limit, the point that he touches is compared by the computer with the correct answer area. If it is within the correct area he is told that he was correct and goes on to the next problem. If the response was not in the correct answer area it is compared with the area of the defined wrong answers (in this example, the other two words). If his response is in this area he is told it is wrong, given the correct answer, and asked to touch it. If his initial response was not in the anticipated wrong answer area or in the correct answer area, then the student has made an undefined answer (i.e., has touched a part of the screen with nothing on it). He is given the same message that he would have heard had he touched a defined wrong answer; however, the response is recorded on the data record as undefined. The student tries again until he makes the correct response; he then goes on to the next problem.

To prepare an instructional sequence of this sort the lesson programmer must write a detailed list of commands for the computer. He must also record an audio tape of all the messages the student might hear during the lesson in approximately the order in which they will occur. Each audio message has an address on the tape and may be called for and played when appropriate (not necessarily in sequential order). Similarly, a film strip is prepared with one frame for each picture required in the lesson. Each frame has an address and pictures can be called for in any order desired.

Table 1 shows the audio messages and film pictures required for our example problems along with possible addresses on the audio tape and film strip. What follows is the computer commands required to present two examples of the problem described above, analyze the student's responses, and record them on his data record. The left column lists actual commands to the computer controlling the instruction. (Labels (L1, L2, etc.) in the column on the far left indicate points which can be branched to.) On the right is an explanation of the results of the execution of these commands. The first problem is explained command by command; the second problem is explained only in outline.

Commands	Explanation
PR	Problem: Prepares machine for beginning of new problem.
LD 0/S1	Load: Loads 0 into the error switch (S1). The role of switches and counters will be explained later.
FP F01	Film Position: Displays frame F01 (picture of a bag).
DT 5,18/bat/	Display Text: Displays "bat" on line 5 starting in column 18 on the CRT.
DT 7,18/bag/	Displays "bag" on line 7 starting in column 18 on the CRT.

Table 1

Audio Script and Film Chips with Hypothetical Addresses

<u>Audio Information</u>

Address	Message
A01:	Touch and say the word that goes with the picture.
A02:	Good. Bag. Do the next one.
A03:	No.
A04:	The word that goes with the picture is bag. Touch and say bag.
A05:	Good. Card. Do the next one.
A06:	No.
A07:	The word that goes with the picture is card. Touch and say card.

<u>Film Strip</u>

Address	Picture
F01:	Picture of a bag.
F02:	Picture of a card.

	DT 9,18/rat/	Displays "rat" on line 9 starting in column 18 on the CRT.
	AUP A01	Audio Play: Plays audio message #A01 "Touch and say the word that goes with the picture."
L1	EP 30/ABCD1	Enter and Process: Activates the light-pen; specifies the time limit (30 seconds) and the problem identifier (ABCD1) that will be placed in the data record along with all responses to this problem. If a response is made within the time limit the computer skips from this command down to the CA (correct answer comparison) command. If no response is made within the time limit the commands immediately following the EP command are executed.
	AD 1/C4	Add: Adds 1 to the overtime counter (C4).
	LD 1/S1	Load: Loads 1 into the error switch (S1).
	AUP A04	Audio Play: Plays message #A04 "The word that goes with the picture is bag. Touch and say bag."
	DT 7,16/→/	Display Text: Displays "→" on line 7, column 16 (cursor pointing at "bag").
	BR L1	Branch: Branches to command labeled L1. The computer will now do that command (EP) and continue from that point.
	CA 1,7,3,18/C1	Correct Answer: Compares student's response with the area 1 line high, starting on line 7, 3 columns wide starting in column 18 on the CRT. If his response falls within this area, it will be recorded in the data with the answer identifier C1. When a correct answer has been made the commands from here down to WA (wrong answer comparison) are executed. Then the machine jumps ahead

to the next PR. If the response does not fall in the correct area the machine skips from this command down to the WA command.

BR L2/S1/1 — Branch: Branches to command labeled L2 if the error switch (S1) is equal to 1.

AD 1/C1 — Add: Adds 1 to the initial correct answer counter (C1).

L2 AUP A02 — Audio Play: Plays audio message #A02. "Good. Bag. Do the next one."

WA 1,5,3,18/W1
WA 1,9,3,18/W2 — Wrong Answer: These two commands compare the student response with the areas of the two wrong answers, that is the area 1 line high starting on line 5, 3 columns wide starting in column 18 and the area 1 line high, starting on line 9, 3 columns wide starting in column 18. If the response falls within one of these two areas, it will be recorded with the appropriate identifier (W1 or W2). When a defined wrong answer has been made the commands from here down to UN (undefined answer) are executed. Then the computer goes back to the EP for this problem. If the response does not fall in one of the defined wrong answer areas the machine skips from this command down to the UN command.

AD 1/C2 — Add: Adds 1 to the defined wrong answer counter (C2).

L3 LD 1/S1 — Load: Loads 1 into the error switch (S1).

AUP A03 — Audio Play: Plays message #A03 "No."

AUP A04 — Audio Play: Plays message #A04, "The word that goes with the picture is 'bag.' Touch and say 'bag'."

DT 7, 16/→/ — Display Text: Displays "→" on line 7, column 16.

UN — Undefined Wrong Answer: If machine reaches this point in

		the program the student has made neither a correct nor a defined wrong answer. He must have touched a part of the screen with nothing on it.
	AD 1/C3	Add: Adds 1 to the undefined answer counter (C3).
	BR L3	Branches: Branches to command labeled L3. (We want to do the same thing to the student for both UN and WA answers. This branch saves repeating the commands from L3 down to UN.)
	PR	Prepares the machine for next (2nd) problem.
	LD 0/S1	These commands prepare the display for the 2nd problem. Notice the new film position and new words displayed. The student was told to "do the next one" when he finished the last problem so he needs no audio message to begin this.
	FP F02	
	DT 5,18/card/	
	DT 7,18/cart/	
	DT 9,18/hard/	
L4	EP 30/ABCD2	Light-pen is activated.
	AD 1/C4	These commands are done only if no response is made in the time limit of 30 seconds. Otherwise the machine skips to the CA command.
	LD 1/X1	
	AUP A07	
	DT 5,16/→/	
	BR L4	
	CA 1,5,4,18/C2	Compares response with correct answer area.
	BR L5/S1/1	1 is added to the initial correct answer counter unless the error switch (S1) shows that an error has been made for this problem. The student is told he is correct and goes on to the next problem. These commands are executed only if a correct answer has been made.
	AD 1/C1	
L5	AUP A05	

	WA 1,7,4,18/W3 WA 1,9,4,18/W4	Compare response with defined wrong answer.
 L6	AD 1/C2 LD 1/S1 AUP A06 AUP A07 DT 5,16/→/	1 is added to the defined wrong answer area and the error switch (S1) is loaded with 1 to show that an error has been made on this problem. The student is told he is wrong and shown the correct answer and asked to touch it. These commands are executed only if a defined wrong answer has been made.
	UN	An undefined response has been made if the machine reaches this command.
	AD 1/C3 BR L6	1 is added to the undefined answer counter and we branch up to give the same audio, etc. as is given for the defined wrong answer.

There are available to the lesson programmer 30 counters that can be used to keep track of a student's performance. During the instructional flow the current values of these counters are used to make branching decisions regarding what stimulus materials are to be presented next. For example, if the correct-answer counter for a particular class of problems has a high value the student may be branched ahead to more difficult topics, whereas for a low value he may be branched to remedial work. These counters can contain any number from 0 to 32,767. They are normally set at zero at the beginning of a course and added to when desired. For example, we used counter 4 (C4) to record overtimes; each time the time limit was exceeded we added one to counter 4 (AD 1/C4).

There are also 32 switches available to the instructor. A switch is either in the 0 or 1 position. These are used to keep track of previous events. For example, at the beginning of a problem we load 0 into S1 (our "error" switch). This lets us know that no error has yet been made on this problem. If the student makes an error on the problem we load 1 into S1. Then if a correct answer is made on his second try we can branch around the command adding 1 to the initial correct answer counter because the error switch (S1) is equal to 1.

There are many features of the CAI system that are not demonstrated by the simplified example we have presented here. The pattern of the problems may vary widely from our sample. At various points in a lesson, criteria may be set which if not met may cause the student to branch to remedial problems or have the proctor called.* Parts of the CRT display may be underlined or displayed in synchronization with the audio messages. Strings of commands which are frequently used may be defined once as a "macro" command and used later by giving a one-line macro command. This cuts down greatly the effort required to present many different but basically similar problems. In fact, a large part of the reading curriculum can be programmed using 80 basic macros.

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*For a general discussion of the problems of devising optimal sequencing schemes see Groen and Atkinson (1966).

Reading Curriculum

The reading curriculum for the CAI system has been developed by a writing team composed of two psychologists, a linguist, two reading specialists, and several teachers and advanced graduate students who have had teaching experience in the primary grades. The materials produced by the group have been developed within the framework of a set of theoretical propositions based on recent developments in psycholinguistic and learning theory. These propositions provide a fairly detailed descriptive explanation of the acquisition of coding schemes that permit the initial reader to correctly pronounce any permissible string of English orthography; they also offer a very tentative view regarding the information-processing activities involved in reading. We shall not review these theoretical propositions here for they have been presented elsewhere along with a survey of relevant research (Hansen and Rodgers, 1965; Atkinson and Shiffrin, 1965).

The curriculum group has now written and implemented more than 200 reading lessons. The lessons are organized into six basic levels (I-VI), and each level is represented by about 35 lessons. Under computer control an average student should progress through a lesson in approximately 30 minutes. However, as one would expect, there are tremendous individual differences: the exceptionally bright student can cover certain lessons in 10 minutes or less, while a student who is encountering unusual difficulties and is receiving extensive remedial work may require three or four 30-minute sessions.

The typical lesson contains the following basic types of instructional materials: 1) letter discrimination and identification;

2) initial vocabulary acquisition; 3) word decoding tasks; 4) syntactic and intonation practice with phrases and sentences; 5) syntactic and semantic practice with phrase and sentence material; and 6) information processing tasks.

The letter discrimination and identification material consists primarily of matching single and multiple-letter strings to models and making same-different judgments about paired-strings of English orthography. This material is presented to insure that the children can recognize each letter of the English alphabet. In this connection a binary-choice game has been devised which enables us to study the process by which the child perceives commonalities in orthographic patterns. The game (a concept-identification task) involves applying simple rules such as "Always select the word that ends with at," or "Always select the word that starts with ma," to the choice between two words. From this game we will be able to obtain data collected at different points in the curriculum about the development of a child's ability to form commonalities about orthographic patterns.

Each new word is introduced along with an appropriate pictorial display. We are interested in evaluating propositions about the effect of iconic references and their associated graphic images on the acquisition and retention processes in initial reading. The overall learning paradigm for this phase of instruction is paired-associate in nature. We will also be using this material to test certain mathematical models which specify optimal sequences for introducing new vocabulary items (Groen and Atkinson, 1966).

The word decoding tasks provide the child with learning heuristics derived from alliterative and rhyming commonalities found within simple monosyllabic words when formed in a matrix layout as exemplified below.

	-ag	-at	-an
b-	bag	bat	ban
r-	rag	rat	ran

These decoding tasks stress the alliterative and rhyming commonalities that result from the commutative properties of consonants when contrasted with simple vowels in pre- and postvocalic positions. The overall instructional sequence provides the child with work on these decoding concepts and also an opportunity for work with simple letter-to-sound correspondence rules as represented in phonic-like material. The decoding tasks are organized so that we can investigate how the child acquires a set of decoding rules that allows him to pronounce any permissible English orthography.

Table 2 indicates how the patterning of consonant structures around English vowels dictates the order in which we introduce new words from one level of the curriculum to the next. This sequencing of the new vocabulary is derived from these psycholinguistic propositions: a) a patterning from simple to more complex vocalic nuclei of the monosyllabic words is easier to learn (i.e., red is easier than read); b) sequencing from single continuant and stop consonants to consonant clusters of maximal complexity controls the learning difficulty (introduce rat before track); c) a sequence that positions consonant clusters prevocalically and then postvocalically will facilitate rehearsal ease and, consequently, acquisition and retention

Table 2

Introduction of Monosyllabic Words

at Various Levels of Reading Curriculum

(C represents any stop, nasal, or spirant consonant;

lower case letters identify the grapheme associated with the vowel)

Level	Consonant (C) Vowel Structure of the Vocabulary						
I	aC	CaC					
II	iC	CiC	CCaC				
III	eC	CeC	CCiC	CaC∉	CCaC∉		
IV	oC	CoC	CCeC	CiC∉	CCiC∉	CaCC	
V	uC	CuC	CCoC	CeC∉	CCeC∉	CiCC	CCaCC
VI			CCuC	CoC∉	CCoC∉	CeCC	CCiCC

(introduce strip before birch).

The syntactic and intonation practice provides each child with systematic presentations of eight basic types of English sentences and their associated intonation patterns. Initially the material is presented with such high-frequency sentence initiators as "I'll," "It's a," "That's a," "They can," etc. These word combinations are pronounced by the children as a single polysyllabic word, and provide them with additional opportunity to practice the nouns and verbs that have been introduced in the vocabulary and decoding sections. This material is paced so that the child can only perform effectively if he proceeds fairly rapidly; this rapid rate encourages him to give a meaningful intonation to the sentence while he pronounces the words.

The syntactic and semantic reading material consists primarily of giving the child practice with the vocabulary, and finding out whether the child understands the meaning of new words as they are introduced. Secondly, form-class items are presented and the child is required to determine whether the word is a noun, verb, modifying word, etc. And finally, new words are presented in a sentence and the child is asked to answer questions that will indicate his understanding of the use of the words as the subject or predicate of the sentence.

The informational processing tasks are presented within the context of simply story material which has been scaled both according to the difficulty of the vocabulary used and to the complexity of the basic idea of the story. After the child has read the story he is asked to retrieve certain information about the plot and principal characters. These questions range from pure recall (Did the spaceman get to the moon?) to interpretation of inferred meanings (Why did the spaceman want to go to the moon?). Sometimes the child is asked to compose an alternative ending for the story, or to continue the story, or to compose possible endings in the event that the plot were changed in some way.

In September 1966 we plan to use the CAI reading program with approximately 100 first-grade children in Brentwood School, which is located in a racially mixed, low-income area of East Palo Alto. Currently a building is being constructed on the school grounds to house the computer system and student terminals. Also, test data is being collected on both those children who will participate in the CAI program and other children who will serve as a control group.

The Brentwood program will be the first full-scale evaluation of our approach. However, in the past two years a number of small-scale studies have been run to test the feasibility of certain aspects of the reading materials, and to determine what special difficulties arise in presenting the curriculum under computer control. The most extensive of these studies involved a computer simulation with twelve five-year-olds and was carried out during the last two months of the academic year 1964-5. The children were run daily for fifteen 30-minute sessions on the lesson materials of Level I. Figure 2 presents the progress of the twelve students when they were divided into three groups according to the rate at which they progressed through the materials. Even during this very short period of training, it was clear that the children demonstrated marked variations in their learning and retention behaviors. These results were quite consistent with similar results obtained from initial mathematics instruction (Suppes and Hansen, 1965). Table 3 presents the

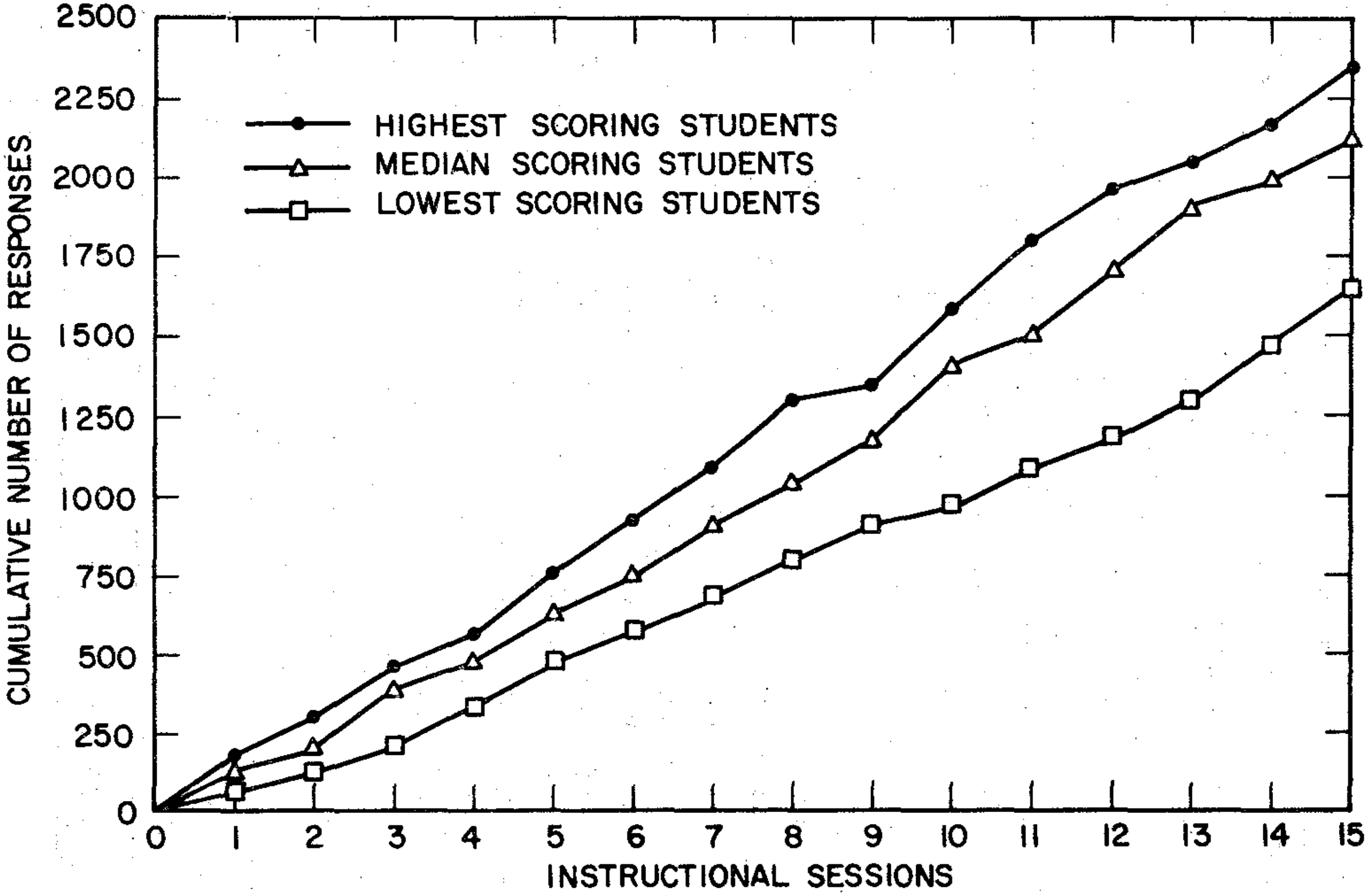

Figure 2. Cumulative Response Curves for the Initial Reading Curriculum

Table 3

Proportion of Correct Responses to Words and Nonsense Syllables by Twelve Five-Year-Old Children

	Rhyming Patterns							
Nasals	mam	man	map	mat	mab	mad	mag	
	1.00	.969	.946	.930	.944	.946	.875	.949
	nam	nan	nap	nat	nab	nad	nag	
	.828	.935	.978	.872	.770	.920	.958	.894
Stops	Pam	pan	pap	pat	pab	pad	pag	
	.936	.891	1.00	.839	.667	1.00	.773	.869
	tam	tan	tap	tat	tab	Tad	tag	
	.875	.884	.936	.908	.740	.800	.981	.875
	cam	can	cap	cat	cab	cad	cag	
	.941	.915	.903	.970	.955	1.00	.897	.934
	bam	ban	bap	bat	bab	bad	bag	
	.888	.895	.850	.695	.762	1.00	.804	.796
	dam	Dan	dap	dat	dab	dad	dag	
	.923	.912	.889	.826	.856	.974	.930	.897
Fricatives	fam	fan	fap	fat	fab	fad	fag	
	.900	.928	.900	.899	.915	.912	.946	.917
	ham	han	hap	hat	hab	had	hag	
	.933	.877	.947	.877	.895	.946	.957	.896
	Sam	san	sap	sat	sab	sad	sag	
	.921	.926	.859	.863	.919	.897	.929	.900
Semivowels	ram	ran	rap	rat	rab	rad	rag	
	.941	.770	.966	.891	.850	.941	.803	.856
Totals	.919	.914	.929	.891	.841	.931	.904	

mean proportion of correct responses of the words and nonsense syllables used in these reading lessons. The nearly equivalent proportions for nonsense syllables in comparison to words suggests that these materials are allowing the children to acquire fairly general decoding schemes.

Discussion

As mentioned earlier, our immediate objectives are (1) to evaluate the feasibility of computer-based instruction in initial reading when carried out over an extended period of time and (2) to collect reliable learning data on a wide range of reading tasks such as letter-string discriminations, acquisition of an initial reading vocabulary, transfer effects on new vocabulary items, and comprehension of phrases, sentences, and stories. These data will be used to revise and elaborate the curriculum, and will also provide a data-base against which to evaluate the many different models that have been proposed for one aspect or another of the reading process. Hopefully, a detailed evaluation of some of these models will lead to a more integrated theoretical framework for viewing reading.

Related to the evaluation of models to describe the reading process is the problem of developing a theory that will predict conditions under which a given instructional procedure optimizes learning. A theory of this type has come to be called a theory of instruction. It has been pointed out by several authors (see articles in Gage, 1963, and Hilgard, 1964) that one of the chief problems of educational research has been a lack of theories of instruction. Bruner (1966) has characterized a theory of instruction as a theory that sets forth rules concerning the most efficient way of achieving knowledge or skill; these rules should be derivable from a more general view of learning. However, Bruner makes a sharp distinction between a theory of learning and a theory of instruction. A theory of learning is concerned with describing learning. A theory of instruction is concerned with prescribing how learning can be improved. Among other things, it prescribes the optimal sequence in which to present the materials to be learned and the nature and pacing of reinforcement.

The reading curriculum incorporates a wide array of screening and sequencing procedures designed to optimize learning. These optimization schemes vary in terms of the range of curriculum materials included, and it has been convenient to classify them as either short-term or long-term procedures. Short-term procedures refer to decision rules that are applicable to specific problem formats and utilize the very recent response history of a subject to determine what instructional materials to present next. Long-term optimization procedures are applicable to diverse units of the curriculum and utilize a substantial portion of the subject's response history to specify the path he is to take through the major units of the curriculum.

As an example of a short-term optimization procedure, we shall describe one that follows directly from a learning theoretic analysis of the reading task involved (Karush and Dear, 1966). Suppose that we have a list of m words to be taught to the child, and have decided that instruction is to be carried out using the problem format described earlier in the section of "Lesson Preparation and Data Recording." In essence, this problem format involves a series of discrete trials where on each trial a picture illustrating the word being taught is presented on the projector screen, and three words (including the word illustrated) are presented on the CRT. The student makes a response from among these words and the trial is terminated by telling him the correct answer. If N trials are allocated for this type of instruction, how should they be used to maximize the amount of learning that will take place? Should the m items be presented an equal number of times and distributed randomly over the N trials, or are there other strategies that take account of idiosyncratic features of a given subject's response record? If we assume that the learning process for this task is adequately described by the one-element model of stimulus sampling theory, and there is evidence that this is the case,* then the optimal presentation strategy can be prescribed. The optimal strategy is initiated by presenting the m items in any order on the first N trials and a continuation of this strategy is optimal if and only if it conforms to the following rules:

1. For every item, set the count at 0 at the beginning of trial $N + 1$.
2. Present an item at a given trial if and only if its count is <u>least</u> among the counts for all items at the beginning of the trial.
3. Following a trial, increase the count for the presented item by 1 if the response was correct but set it at 0 if the response was incorrect.

Even though these decision rules are fairly simple they would be difficult to execute without the aid of a computer.

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*See Atkinson, Bower, and Crothers (1965); Atkinson and Crothers (1964); Atkinson and Estes (1963); and Hansen (1964).

This is only one example of the type of short-term optimization strategies that have been incorporated in the reading curriculum. Some of the other schemes are more complex, involving the application of dynamic programming principles (Smallwood, 1962), and use information not only about the response made but also the speed of responding. In some cases these optimization schemes can be derived directly from learning theory, whereas others are not tied to theoretical considerations but are based on intuitive considerations that seem promising. The data to be collected next year will make it possible to evaluate these schemes and in turn the learning theories and intuitions on which they are based. For a general discussion of short-term optimization procedures, their relation to learning theory, and problems involved in their evaluation, see Groen and Atkinson (1966).

Even if short-term optimization strategies can be devised which are highly effective, we are still a long way from specifying a total reading curriculum that is optimal for learning. It is, of course, possible to optimize performance on each unit of the curriculum while at the same time sequencing through the units in an order that is not particularly efficient for learning. The most significant aspect of curriculum development is with regard to long-term optimization procedures where a substantial portion of the response history on a subject can be used to determine the best order for moving through major units of the curriculum, and also to designate the proper balance between drill and tutorial activities.

In the present version of the reading curriculum we have introduced several long-term optimization procedures. Unfortunately, the theoretical rationale for these procedures is not well worked out and is open to serious question. We hope, however, that these procedures and those suggested by future research will help to lay the ground work for a theory of instruction that will span the diversity of concepts and skills found in an elementary school subject such as reading. Such a theory will have to be based on a rich and highly structured theory of learning, plus an optimization strategy that follows logically from the theory and is compatible with current educational goals. The development of such theories is a major undertaking, and in a pragmatic sense, is the goal of a psychology of learning.

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