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ABSTRACT

This paper analyzes a typical school spelling task in terms of an information processing model of spelling performance. Based on principles embodied in a computer simulation program previously reported (SPEL by Simon and Simon) the model proposed here has been expanded to try to account for many more kinds of student error than were possible with the original model. It explores the nature of the speller's internal representation of the word to be spelled, the information one must have in memory about the target word in order to produce a correct spelling, and the organization of the processes available to use the information to produce a spelling and to verify its accuracy. Examples of errors from children's spelling tests are used to discuss sources of errors in terms of the model. Ways in which the model may be adapted to explain performance in other kinds of spelling tasks and some implications for instruction and curriculum design are suggested. (Author/HOD)

LEARNING RESEARCH AND DEVELOPMENT CENTER

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Abstract

This paper analyzes a typical school spelling task in terms of an information processing model of spelling performance. It explores the nature of the speller's internal representation of the word to be spelled, the information he must have in memory about the target word in order to produce a correct spelling, and the organization of the processes available to use the information to produce a spelling and to verify its accuracy. Sources of error in the execution of the task, with examples of errors from children's spelling tests, are discussed in terms of the model. Ways in which the model may be adapted to explain performance on other kinds of spelling tasks and some implications for instruction and curriculum design are suggested.

The intended audience includes teachers, curriculum designers, and educational and cognitive psychologists.

Contents

SPELLING--A TASK ANALYSIS

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Spelling--the ability to translate words of the oral language into "correct," or standard, symbols or sets of symbols--is a basic literacy skill whose development through education often proves slow and painful to educators and students alike. Although less crucial than reading problems, spelling problems persist throughout the school years over the whole range of ability groupings. Search for the source of problems and for ways to speed up the skill development process has led to a sizable body of research over a long period of years (Horn, 1969). Scholars have attributed the difficulty to the nature of English orthography (Hodges, 1972), have explored the efficacy of different ways of teaching spelling (Petty, 1968), and have carried out a large number of studies of the nature of spelling errors (Cahen, Craun, & Johnson, 1971). Spelling curricula are continually being revised on the basis of research results, but the problems persist.

This research, largely empirical in nature, has dealt mainly with the environment in which spelling takes place or has concentrated on the output of spelling behaviors. Recent developments in cognitive psychology suggest that attention now be turned to the individual speller--his knowledge and processing capabilities. A pioneering effort to put individual spelling behaviors into systematic form is described in "A Model for the Analysis of Spelling Behavior" by Personke and Yee (1966).[1] Using the

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[1] Implications of the model for instruction have been drawn (Personke & Yee, 1968), and applications are being implemented (Yee, Shores, & Baker, 1973).

terminology of general systems theory, the authors propose a very general model which defines behavior as a set of "channels," or feedback loops, connecting memory with the processes of choosing the channel, scanning, responding, and checking.

The intent of this paper is to develop a theory of spelling incorporating these "systems" ideas, but specifying in detail the contents of memory and the nature of the processes that can lead to the production of a spelling. It does this by analyzing a spelling task in terms of information and processing requirements necessary for performance. Based on principles embodied in a computer simulation program previously reported (Simon & Simon, 1973), the model proposed here has been expanded to try to account for many more kinds of student error than was possible with the original model.

This model may be thought of as a first approximation to a description of a human speller--a system with sufficient capability to perform a precisely specified spelling task, with "correctness" of the product determined by precisely specified limitations on the knowledge and on the efferent, afferent, and processing characteristics of the performer. No claim is made that this is a unique, or even a complete, model of performance. Many variations are possible in the knowledge assumed, the form of its storage in memory, the nature of the processes brought into play, and the organization of these processes into larger systems. Too little is known about some of the components of the system--for example, the organization of short-term memory and the relation of short-term memory to the motc system--to construct a definitive model. Nevertheless, the model developed here is sufficient to explain much student spelling behavior.

The Theory

This study uses the theoretical framework described by Newell and Simon in Human Problem Solving (1972), which may be summarized briefly:

> The theory assumes that a human is capable of performing a relatively small number of elementary information processes--cognitive manipulations of symbols--which are organized into groups of processes (programs) that guide their performance. These processes use a short-term memory capable of holding only a few items of information, and a large long-term memory organized as a network of associations.

These statements represent the kernel of the theory of human information processing used in the analysis undertaken here. Additional elements of the theory can best be described in a spelling context.

Internal Representations

Stimuli from an input channel--vibrations on the retina or eardrum--are recoded into internal representations available for processing and for storage. Recognition takes place when the representation of an incoming stimulus finds a matching representation in memory. It is useful to think of long-term memory as a reference book with a good index and the initial encoding of an item presented for recognition as the index word (I-word) that guides search of the memory to relevant information. The I-word is the set of stimulus features used for recognition.

The form of the I-word depends on the kind of stimulus--whether a written or printed word, a scene, a language or non-language sound, a smell, a taste, or a feel. Associated in long-term memory with each I-word may also be representations of the I-words derived from other sensory modes. Many of the processes occurring in spelling require auditory representations of the word itself and its components, as well as related information, e.g., the names of the letters, one or more speech sounds (phonemes) associated with each letter name or shape, the word in the oral vocabulary, or the verbalization of spelling rules and mnemonics. For other processes, visual representations must be available--the shapes of the letters and more or less complete information about the ordering of letters in the word. To produce an output, motor representations of the whole word or its components must be available. Semantic information may be represented in more than one mode.

Information Requirements

Information as used here comprises all representations in association memory. It is of two general kinds--data and programs.

Data are facts stored in long-term memory--the memory stock or memory store. The facts used in spelling include (a) semantic information--the meaning of the word itself and of directions such as "Spell" or "Write the word" that define the task environment; (b) representations derived from the senses, for example, the names and shapes of the letters of the alphabet; and (c) relations among these representations such as the sounds associated with each letter or rules for forming plurals.

Programs are organized series of processes that the speller can call on in order to perform the task. The components are such elementary information processes as: find on a list; put on a list; compare two pieces of data to determine if same or different and do one thing if same, something else if different: and so on. These elementary processes are analogous to programming instructions in a high level computer language; their usefulness for expressing theories of human information processing has been amply demonstrated by computer simulations of people solving problems (Newell & Simon, 1972), understanding instructions (Hayes & Simon, 1974), and performing other real-life tasks described in the recent literature.

The Stock of Spelling Information

The data that are potentially relevant as input to the spelling processes are listed in Table 1, but require fuller explication.

Table 1

The Stock of Spelling Facts

Task environment

Meaning of all words and phrases used in directions to perform the task

Alphabets

Names of letters (auditory)
Shapes of letters (visual)
Shapes of letters (motor)

Sets of relations

Isolated speech sounds with associated letter name/shape
At least one letter per sound
OPL (optional pattern list) for each sound

Words

Auditory representation--complete if in speaking vocabulary
Visual representation--complete or incomplete
Motor representation--whole word or word part
Meaning(s)--variant spellings for homophones
Mnemonics and related words
Pointers to rules and general mnemonics

Rules and general mnemonics

Rules
Syntactical endings
Pronunciation
Orthography
Writing conventions
Mnemonics that apply to classes of words or sounds

External sources of spelling information

Sources themselves--dictionaries, glossaries, atlases, and so on
Where to find sources
How to use sources

The Task Environment

Most spelling behavior occurs in the course of producing a written communication. In the intermediate grades, we take for granted that children know the meaning of such phrases as "Use your best spelling," "Check your spelling," and "Proofread your paper." These meanings are acquired near the beginning of a child's school career through the medium of the oral language embedded in relevant situations. The meanings of all words and phrases required by the task environment must be in the information stock.

Alphabets

The building blocks of our written language are the letters of the alphabet. To use these building blocks in reading and writing, one must have stored in memory several alphabets, the members of each of which can be put into one-to-one correspondence with members of one or more of the others. The names of letters are auditory representations. There will be two kinds of alphabets of letter shapes--visual representations and motor representations. Both of these kinds of representations will include alphabets of capital and lower case and of "manuscript" and "cursive" letters.

Sets of Relations

There must also be stored sets of relations, or mappings, that relate letters to sounds (for reading) and sounds to letters (for spelling). For purposes of English spelling, most sounds require an association with more than one letter or letter cluster (graphemic options)--what we call optional pattern lists (OPLs) for each phoneme. Examples of what we mean by OPL are shown in Table 2. These are adapted from a comprehensive list of options that occur in a large corpus of English words compiled by Hanna, Hanna, Hodges, and Rudorf (1966).

Table 2

Examples of Optimal Pattern Lists (OPLs)

Phoneme	Illustrative Word	OPL
/long A/	ale	a-e, ai, ay, a, eigh
/long E/	eve	e, ee, ea, e-e, i-e, ie, ei
/f/	fill	f, ph, ff, lf, gh
/r/	rat	r, rr, wr

The Word Store

When normal children start to school, they already have in memory a large oral vocabulary, which expands rapidly as they are exposed to new experiences that are verbalized by teachers, other adults, and peers. In our scheme, each word in the oral vocabulary serves as an index to a number of associations with that word in memory. This index word is a complete, if not always accurate, auditory representation. That is, the representation may be a sound string as heard in the child's home or language community, or as he, himself, pronounces it, rather than a standard or dictionary pronunciation.

Words that the child has learned to read will have associated with them enough visual information so that he can recognize their printed or written forms. This information may be complete or incomplete, depending on his previous experience, i.e., his attention to the letter forms and his need to recall them. It may include information about capitals, hyphens, and the like. For words that he has written many times, a complete motor representation of the whole word, as distinct from its component letters, may be stored. Associated auditory, visual, and semantic information may make it possible to distinguish different spellings for different meanings when the word is a homophone. This model assumes that such words are flagged or marked in some way for special attention in spelling.

For even the best of spellers, the writing of parts of some words requires special attention--recourse to a mnemonic such as "a friend to the end"; a morphological relation such as "a president presides"; or a rule such as "when forming the plural of a word ending in consonant-y, change y to i and add es." This model postulates that the ambiguities in such words are flagged to assure that special attention will be given to their spelling. In some cases, as in the first two examples, the clue will be stored in direct association with the words; in others, as in the third example, the flag is in the nature of a pointer to a store of spelling-relevant information where a clue may be sought.

Rules and General Mnemonics

A number of rules and mnemonics that apply to classes of words are taught in every spelling curriculum to help resolve ambiguities. These include rules for adding syntactical endings, e.g., -ing, -ed, -s; orthographic rules, e.g., q is always followed by u in English words; mnemonics, e.g., the "i before e" rule; rules of pronunciation, e.g., c is soft when followed by e, i, or y; and rules of capitalization and for forming contractions. Sometimes these are accompanied by exceptions to the rules. In this model these kinds of information are stored in a "spelling aids" file. The categories listed are far from definitive, are not necessarily mutually exclusive, and the order is arbitrary.

External Memory Sources

The stock may also include external sources that are available for checking a produced spelling with a standard--for example, teachers or parents or peers, option charts or spelling reference tables, dictionaries, glossaries, and the like, as well as information on where to find and how to use these sources.

Much of the information listed in Table 1 (page 5) is normally acquired in the process of reading, writing, speaking, and instruction in the language arts. If the motor or visual representations are complete, the other kinds of information may not be used; but for words written for the first time, or rarely, the availability of some sound-symbol correspondences is essential, and the presence or absence of the other kinds of information in stock may make the difference between good and poor spellers.

Access to Spelling-Relevant Information

The theory of memory accepted here assumes that when one recognizes an index word in the context of the spelling task, he may take a track that makes available information somewhat different from what would be available were the word presented in some other context. For example, in reading and speaking it is not necessary to distinguish variant homophonic spellings--rode and road are both pronounced /rōd/--nor to note the variant spellings for which mnemonics are important--relieve and receive. And the unstressed vowel, the schwa, seldom gives a clue to its spelling pattern. Since, however, most words are read more frequently than they are written, complete visual information about the spelling may be available in the context of a reading (recognition) task. The function of proofreading in the model is to provide access to as much visual information as may be contained in the reading recognition vocabulary by putting the checking behavior in the context of reading.

A Spelling Program--SPEL2

How information in the stock will be used for spelling depends on the task environment. The basic, or elementary, information processes that will carry out the task--search, find, compare, and so on--will be used many times in many combinations. Table 3, in programming outline format, and Figure 1, in flowchart form, show how these processes may be organized to perform a typical school spelling task, namely: The teacher (or tape or experimenter) dictates a word, uses it in a sentence, pronounces the word again, and the student writes the word. This task has been partially simulated on a computer as Program SPEL (Simon & Simon, 1973); to indicate the relationship of the program described here to the earlier one, we call this SPEL2.

Table 3

SPEL2 -A Program to Produce a Written Spelling From Dictation[1]

PERCEIVE (Input Oral word, context, oral word repeated)

ATTEND	Attend to Input Encode or recode sound stream into auditory representation, call it I-word
RECOGNIZE	Look for match in memory If match not found, Go to MODIFY
CHECK	Check for homophone flag If none found, Go to GENERATE
CONFIRM	Do ATTEND to get context, Go to GENERATE
MODIFY	Check Times Tried Counter (TTC) If TTC = 0, 1, or 2, add 1 to TTC, Go to ATTEND
FIXATE	Rehearse sound string, attempt to store I-word with as much context as possible, Go to GENERATE

(MORE)

[1]Notes on reading the program outline:
Capitalized item headings are names of major subroutines.
Instructions are executed in order from top to bottom, except where a conditional branching instruction is encountered.
"Do" means "execute named routine, return to same place in program and execute next instruction."
"Go to" means "skip to named routine and proceed from there."
(Figure 1 illustrates this program in Flowchart form.)

GENERATE (Input: I-word)

DECIDE	Is whole-word information available?
	    If complete motor program available, Go to PRODUCE
	    If complete visual information available, let symbol-string equal
	        OP-string, Go to RECODE

SYLLABIFY	Factor word into syllabic segments, call each SYL
	Select first available SYL
	    No more, Go to RECODE
	If motor program for SYL available, mark SYL "done," Do PRODUCE,
	    Go to SYLLABIFY
	If complete visual information for SYL available, call it OP
	    mark SYL "done," Do ASSEMBLE, Go to SYLLABIFY

PHONEME	Factor SYL into phonemes, call each F
	Select first available F
	    If no more, Go to SYLLABIFY
	Find OPL for F
	    If visual information (V) available, match on OPL of F
	        If match succeeds, call it OP, mark F and V "done,"
	            Do ASSEMBLE, Go To PHONEME
	    Check I-word for "get aid" flag
	        If present, Do GETAID
	    If clue not found in GETAID, select first symbol on OPL,
	        call it OP
	    Mark F and V "done," Do ASSEMBLE, Go to PHONEME

GETAID	Identify "get aid" flag
	    If flag points to Word associations, search network for clue
	    If not, search Rules and Mnemonics file, as indicated
	    If clue found, call it OP

ASSEMBLE	Store OP on right-hand end of symbol string, call it OP-string
RECODE	Recode OP-string for output, Go to PRODUCE

PRODUCE (Input: OP-string)

Execute motor program

TEST (Input: written word)

PROOF	Search I-word associations for reading recognition information Match symbols left to right If match found, EXIT

CHECK	Search external source information in stock, select source,
	    go there, find word
	Match symbols
	    If match found, EXIT

RECHECK	Call uncertain symbols F, Go to PHONEME Change uncertain symbols in written word Go to TEST

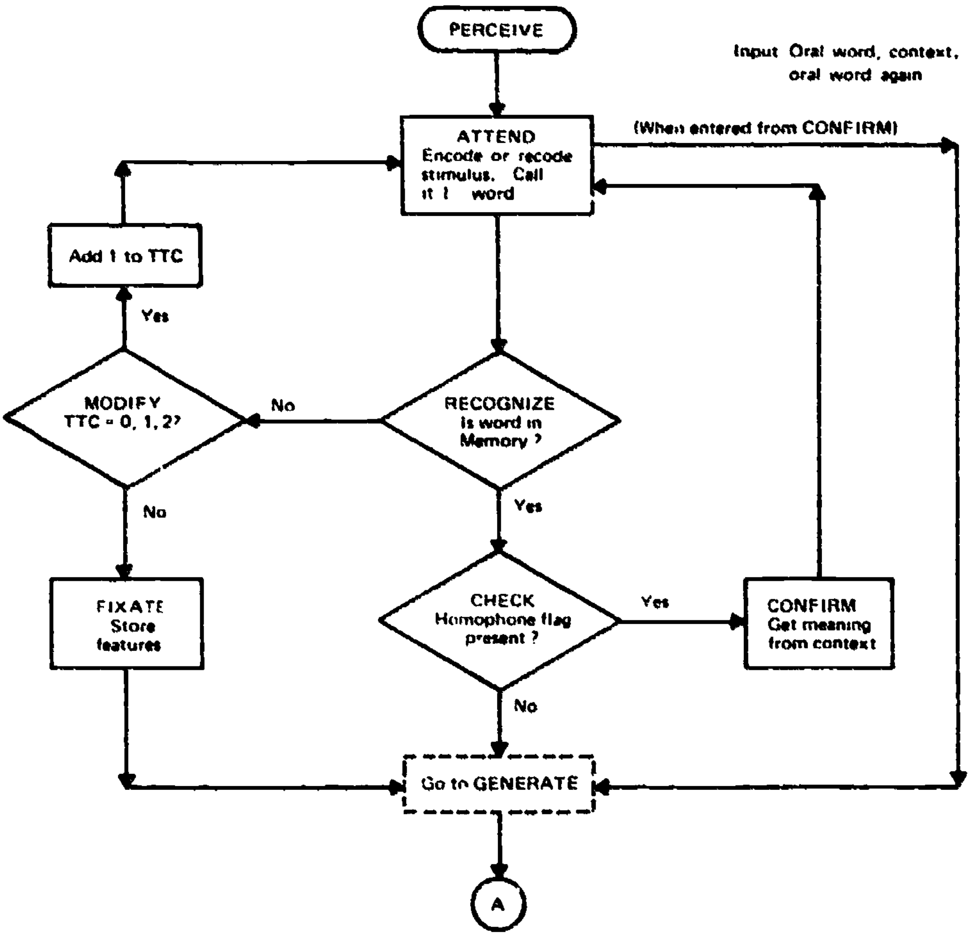

Figure 1. SPEL2--A program to produce a written spelling from dictation.

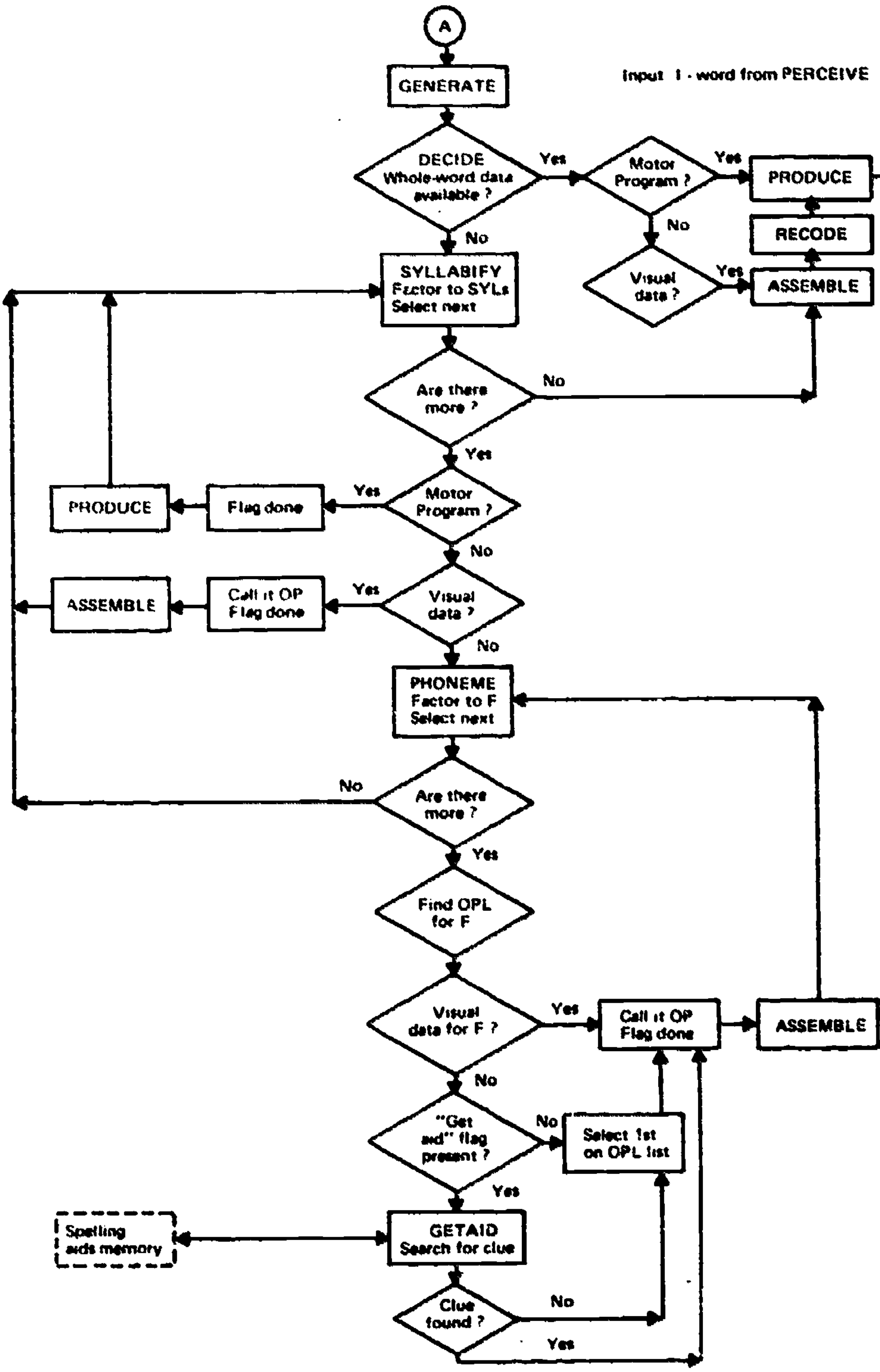

Figure 1 (Cont'd). SPEL2--A program to produce a written spelling from dictation.

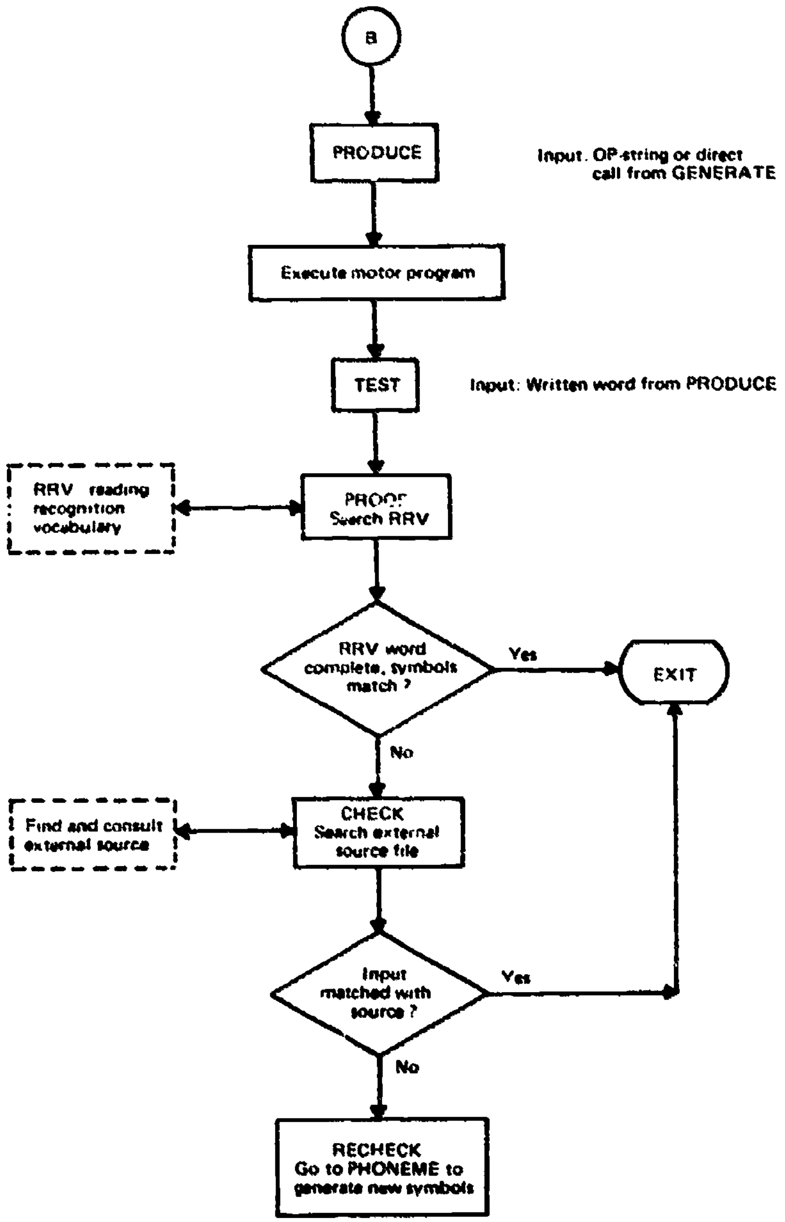

Figure 1 (Cont'd). SPEL2--A program to produce a written spelling from dictation.

The processes to be described are executed exceedingly rapidly and well below the level of consciousness.

Organization

The program consists of five major parts, or program routines: Perceive recognizes the word by finding the index word (I-word) in memory if it is in the student's oral vocabulary; otherwise, it fixates the sound string; Generate finds the graphemes required by the spelling task; Produce activates the motor program for writing the word; Test checks the production for accuracy.

Perceive

"Perceive" is a word used frequently in the psychological and educational literature but seldom defined. In the general literature it is sometimes used as a synonym for comprehend or understand, but in psychology, as in this program, it connotes the processing of information received through the senses. The processing that occurs is here defined precisely by the program.

The sensory inputs to this task are received through the auditory mechanism--a word, a sentence containing the word, the word repeated. When the student first hears the word, he transforms the sound stream into an internal representation--the I-word. The transformation mechanism assumed here is that the sensory input is encoded, with great rapidity, as a set of detectable "features." This feature set may represent no more than a phoneme string that can be repeated, or it may represent as much as a well-known word or phrase. If this feature set finds a matching set in memory, it is "recognized."

If the I-word is recognized as a familiar word, the program checks for a homophone marker or flag; : lagged, the student knows that he must attend to the context sentence to determine which alternative spelling to select.

If the I-word is not recognized, this program gives him several chances to renew the sound stream in short-term memory or to attend to the context and to the repetition of the word, to change some features of the sound stream or add features, and to try again to find a word in memory that corresponds. (The exact number of times any individual tries to find the word no doubt varies greatly, depending on facility with language and on attention and motivation; but for purposes of the program, the number three was selected.) If the speller still has not found a corresponding word in memory, he fixates the representation and sets up a new image in memory, together with such information provided by the context sentence as there has been time to attend to and to store.

Generate

Input to the Generate routine are the I-word and the associations to which the task instructions ("spell") point.

Decide. In this version of the model, the first activity is to search the association net to see if a complete motor program is available for immediate production--subroutine Decide. This provides a shortcut that accounts for what is variously called "kinesthetic by-pass" (Personke & Yee, 1966), hand spelling, automatic spelling, an integrated motor response, and so on, of an overlearned word. If such a shortcut is found, no further generation processing takes place, and the motor system takes over to produce the letters. If no motor program is available, search is made for a complete visual representation which, if present, is immediately recoded for output and produced by the motor system.

Syllabify. It seems very likely that although whole-word information is not immediately available, programs may exist for shortcuts to the production of individual syllables or morphs that have been "overlearned" such as the common prefixes and suffixes. We therefore provide a routine that factors the word into segments: for each in turn it tries to find first a motor program, and failing that, a complete visual representation. The syllable may be recoded and produced immediately, or it may be stored for output when the word is complete; we here assume the latter.

Phoneme. Input to this routine is the syllable for which no shortcut has been found. This is the heart of the spelling task and incorporates the features of the original SPEL program, with the added opportunity to use related information as aids to grapheme choice.

The syllable is factored into discrete phonemes; for each in turn the optional pattern list (OPL) of the phoneme (F) is brought into short-term memory, together with any visual information available from the analogous syllable of the I-word; members of the OPL are matched in turn with the visual information; if a match is found, the selected spelling pattern is put on a list for output.

Getaid. If no match is found, the program checks the I-word for a flag or flags that indicate that help may be available at this point. If a marker is present, the program calls the subroutine Getaid to search memory for a clue. (The search routine is not described in detail here for the reasons suggested in the "rules and general mnemonics" section [page 8]. An implementation of this program would require that some assumptions be made about the nature and the order of search.) If a clue is found, the symbol or symbols are sent to the assembly string and the program goes on to process the next phoneme.

Lacking direct knowledge or clues, the program selects the first option on the OPL, a last-resort feature of the SPEL program, also.

Assemble. This is a small program that stores options at the right-hand end of a string of symbols, the OP-string.

Recode. Recode recodes the OP-string in a form that can be used as input to the motor system.

Produce

This routine calls on the motor system to execute the production of a spelling in the required form. Little or nothing is as yet known about the form of storage at the interface, or the relation of short-term memory to the functioning of the motor system. Detailed description of the processes involved here must await development of relevant theories based on sound data.

Test

In a program of this complexity there are many places where errors of execution may occur (see following section for examples). It is a fact, however, that it is possible to develop skills to find and correct errors before a written message is transmitted to the intended recipient (see, for example, Personke & Knight, 1971). SPEL2 suggests the mechanisms that may accomplish this testing.

Proof. The speller's most valuable resource, both for proofreading in general and for checking his own spelling productions, is his vast reading recognition vocabulary; it is often possible to choose among alternative spellings or to recognize whether a spelling is correct or incorrect even though one had not initially been sure if he had produced a correct one. The Proof routine is a simple matching process between the visual stimulus and the stored visual representation of the word, together with an evaluation. (An alternative proofreading routine might read the word and try to match the symbols with sounds in auditory memory. Since reversals, substitutions, or omissions often result in a nonword or a word not appropriate to the context, an incorrect spelling might be detected.)

Check. The accepted authority for correct spellings is a dictionary of modern vintage: knowledge of other sources of correct spellings may also be in the memory store. If the word as written cannot be found in one of these sources, the Recheck routine cycles back to Generate to produce an alternative spelling which is in turn sent to Test for verification.

Summary of Spelling Processes

We have described here a series of cognitive processes that use information stored in long-term memory to spell a dictated word. The speller first tries to find the word in his long-term memory stock. If he fails, he may modify his auditory representation of the input stimulus and try again to find it in memory. If he decides it is a word he does not know, he will try to fixate the sound stream and add the word to his memory store together with any information he has had time to acquire about it from the context sentence. He may recognize the word as a homophone and distinguish two or more possible spellings from context.

His first step in attempting to write the word will be to see if he can by-pass the more onerous generation process by using a ready-made motor program. If this is not possible, he may try to find shortcuts for syllables: if that fails, he must "sound out" the phonemes and match phonemes to spelling patterns. On words that he has previously read or written, some letter information may be directly available for matching. Gaps or ambiguities in the letter string may be marked with pointers to additional information that will help him make a selection. Lacking other information he will select a spelling pattern from the list of spelling options for that phoneme.

The results of the decision processes for each phoneme will be stored on a list, which, when complete, will be turned over to the motor system to produce a spelling in writing. The production may be tested for accuracy by comparison with information in the reading recognition vocabulary or in an external source, and it may be corrected and retested.

How Spelling Errors May Occur

With Table 3 (pages 10-11) or Figure 1 (pages 12-14) in hand, we can test the plausibility of the model by noting what kinds of errors may be expected at which places in the program and by comparing our hypotheses with actual errors taken from the pretests of a group of fourth-grade children who performed the task. Use of the concepts of the model for purposes of diagnosis of difficulty are suggested.

Errors of Perception

It is easy to see how spelling errors can arise from idiosyncratic mispronunciations--warter for water, shore for sure, unaspected for unexpected. The child has found the oral word in his memory store as he pronounces it and then proceeds to Generate. If he lacks motor, visual, or other information, he produces a phonetic spelling for that pronunciation.

Homophones. We have classified the determination that a word is a homophone (page 15) as a perceptual process because it requires recognition that a particular sound stream has at least two different spellings depending on meaning. Table 4 shows the misspellings on a homophone test produced by a sample of average to low-average fourth-grade spellers. These spellings indicate that most of the misspellings on these words have causes other than misidentification of a member of a homophone pair. Certainly, herd is a much less well known word for 9-year-old suburban children than heard; in fact, herd may well be in neither their spelling nor their reading vocabularies; this, then, must be diagnosed as an options or phonetic error. The five misspellings of whole indicate that the homophonic distinction between whole and hole had been made, but that the correct spelling of whole was not available. One can analyze the other errors in the same way to determine if they are true homophone errors in the sense that a homophonic marker was not present, or if the child made a distinction but simply did not know how to spell the alternative.

Table 4

A Sample of Errors on a Homophone Test

Dictated word	Errors by subject					
	RS	DD	DH	KK	WG	EK	BZ
hole	howl						
whole	houl	hule	hool	holl			howl
roll	rool	rool	role				
deer		dear		dear			
die					dye		
fair	fure				fare		
hay	haw						hey
hour							
meet							
sea							
seem	team						seam
roal				rite			
sew	sow		saw	sow	sow		so
won				whone			
break	brako		brake	breek	brake	breack	brake
knew	now						
heard	herd					nerd	

Unknown words. Some of the spelling words were unlikely to have been in either the speaking or reading vocabularies of these children. Examples of the kinds of errors that can occur when one is faced with the problem of fixating the sound stream for an unknown word can be found in the pretests of a child who is a generally competent speller and a good reader: Yosemite was written Yousemetee; thorax was written florax, and nymph was written minth--both of the latter involving sound changes.

Other perception errors. Except for these "nonsense" words, the number of errors that may be attributed to perceptual errors as defined here is generally small--perhaps not more than 1 in 100 errors for most children on known words. There are, however, some children who produce a number of "nonphonetic" spellings of common words--errors that would seem to be traceable to errors in perception. For example, one child with recognized perceptual deficits was given the word head and wrote hare; if hare is interpreted as a phonetic rendering of hair, this might indicate that the well-known word head was recognized, but that the search process carried her one step deeper into memory so that the subordinate category, hair, was brought up into short-term memory for application of the generation process. For children of this sort, careful analysis of the probable cause of error in each word must be made and special instructional techniques must be devised.

Errors of Generation

The Decide routine provides a by-pass of the full spelling generation process if a motor program for output is immediately available; this may operate on syllables or morphs of a word as well as on whole words.

Phonetic misspellings. Three-quarters or more of the errors of most children are "phonetic," i.e., represent incorrect selection of spelling patterns for the ambiguous phonemes--notably the unstressed vowel and double versus single consonants. This proportion holds especially for the good and medium spellers. For example, on one pretest of an upper-medium good speller we find offic, distens, prinsses, sentance, and so on. It also holds for a few of the poor spellers; for example, on the pretests of one such child we find that almost every word is spelled with incorrect options, with such results as alwase, wagen, beter, anamal, and so on. For most of the poor spellers, however, the proportion of options errors is greatly diluted with errors of perception, placekeeping, or production.

Misapplication of spelling aids. Misapplication of a generally useful rule is rare, but a striking example is found in the pretest of one child on the list of words that was supposed to allow the "induction" of the "drop the silent -e before adding -ing" rule. This child had done quite well on the previous list where he had to double the final consonant before adding -ing, and he proceeded to apply what he had "learned" by writing havving, ridding, movving, livving, and so on, for every single word in a 17-word list! This illustrates the care that must be taken in presenting even the most universally useful rules to children of this grade level.

Other errors arise, even in adult spelling, from failure to note exceptions to some generally useful aids--failures that result in such frequent adult misspellings are truely, duely, proceedure, and sieze (Masters, 1927).

Nonphonetic spellings have long been a puzzlement to theoreticians and a concern to teachers. This model enables us to point to some places in the spelling process where we may look for an explanation of such spellings.

Nonphonetic spellings take a number of forms--the wrong word, sound changes, reversals and transpositions, omissions of letters and of syllables, addition of letters and syllables, truncation of a longer word, and a large number of errors that are difficult to classify. Individual performance models will eventually have to account for all the idiosyncratic errors that occur, but let us go back to the general model to see how many of these kinds of errors may be explained.

The wrong word and sound changes we have already attributed to errors in the perceptual processes. Truncation such as tent for attention may also take place at the perceptual level--failure to recognize a sound stream as a word one knows how to spell and lack of time to fixate an auditory image. A truncation such as know for knowledge would seem to indicate a failure of the program to complete processing after a known morph had been generated. A spelling such as burgalar seems to be a direct transcription of an idiosyncratically pronounced word. A spelling such as kniedge for knowledge might be expected to occur at the interface between the perceptual and the generation programs; here enough of the input word was stored so that the kn and the edge were available, but the phonemic information in the middle of the word was lost.

The description of the SPEL algorithm noted, "There are a number of fussy programming details in the algorithm that relate to keeping track of current locations in the phoneme list and recognition list, and keeping track of the readings that have been tried. These 'programming details' may not be without psychological significance" (Simon & Simon, 1973, p. 131). Omissions of letters and syllables, as well as reversals and transpositions, may be due to failures of the housekeeping processes to operate in an orderly fashion. Other possible sources of reversal and transposition errors, to which some children are particularly prone, may be sought in the processes that store the graphemes in order on the output list, or they may occur at the interface between the Generate and the Produce programs. As noted above, more needs to be known about the connections between short-term memory and the motor system to account for these kinds of errors.

Errors of Production

The most obvious of the production errors are those of handwriting. In manuscript writing, confusion of b's and d's is notorious; in some cases this may be an error of auditory perception, but for the child who can spell boy correctly aloud but writes doy, the motor program must be at fault. Every teacher can point to habitual and idiosyncratic handwriting confusions by some children--confusions such as h-k, a-o, e-i, and m-n. This is an area that calls for further research.

Errors of Checking

The checking routine presents a reading rather than a spelling task. It is a simple process of matching visual input from the written word with information in the reading recognition vocabulary. Errors here may result from failure to attend to each and every grapheme in the production or from incomplete visual representations in memory. Since the children whose tests we have at hand were not encouraged to proofread their tests before handing them in, we have no information on what changes, if any, they might have made if they had performed such a test of their productions.

Summary of Sources of Processing Error

We can now summarize the major ways in which errors may occur in the performance of a spelling-from-dictation task if we assume that spelling is performed in accordance with the model described. Errors of perception, as defined here, can arise from idiosyncratic mispronunciations that are then spelled phonetically by the succeeding generation processes, from failure to fixate accurately or completely the input sound stream, from failure to note a homophone marker or to select the correct homophonic spelling, and occasionally, from failure of the search process to stop when it finds the index word.

There are many possibilities for errors of generation. Most frequent is selection of the incorrect spelling option for an ambiguous phoneme. Others are processing of phonemes in an order other than that present in the stimulus word stream and errors in marking processed phonemes or visual representations, either of which may result in an incorrect ordering of graphemes on the OP-string for output. Misapplication of spelling aids is another, but much less frequent, source of error, although failure to flag a word for which a mnemonic is available is not infrequent--e.g., relieve-receive.

Errors of production arise from the inaccurate formation of letters in handwriting and at the interface between the cognitive and motor systems.

In addition to these identifiable sources of error, anyone who has written and debugged a computer program knows how many subtle ways there are in which errors can occur. With the use of the general model described here, we should eventually be able to do a much more thorough job of diagnosis of children's spelling problems.

Adaptation of the Model to the Analysis of Other Tasks

This description has attempted to do two things: (a) to analyze a particular spelling task in terms of the kinds of knowledge and processing capabilities required for performance of the task, and (b) to suggest for any individual speller where gaps in information may occur and how particular subprocesses may be omitted or performed in incorrect order. Veridical analyses of performance must be deduced from each individual's performance; some examples of how this may be done have been suggested. As a task analysis the technique used here can prove useful in analyzing other kinds of spelling tasks, as the following examples show.

Self-generated spelling, of the sort used in all independent writing activities, would require all the same kinds of knowledge and processing of the spelling-test task except that there is no sensory input--the writer knows what word he intends to write, its sound in implicit speech, and its meanings. The production program might have to be expanded to include other kinds of motor programs--typing, for example.

An oral spelling test would be identical with the model task except for output--the motor program must include production of letter names through the articulatory mechanism.

This kind of task analysis can also be applied to helping groups of children whose normal pronunciation differs from that of spelling series authors or of standard dictionaries--the regional or community accent problem. It suggests, for example, that additions to or changes in the standard optional pattern lists may be useful, notably, the schwa-*r* sound.

An interesting exercise is to apply this technique of analysis to spelling in other orthographies: an orthography such as Italian in which each phoneme, with a very few exceptions, has a single spelling option; syllabic orthographies such as the Japanese *kana* systems; an ideographic orthography such as the Chinese. It can be done, but development of the idea is outside the scope of this paper.

Implications for Instruction

Since a test is an assessment of what children know and can do, and hence of the outcome of instruction, an analysis of a test-taking task will provide clues as to what must be included in prior instruction. The analysis of the spelling-test task undertaken here carries several implications for instructional content and techniques and suggests reasons why some strategies of instruction are more successful than others.

1. It is usually futile to test children on words unlikely to be in their reading vocabularies. Because of the nature of English orthography, visual information about the required spelling options for the ambiguous phonemes is necessary if performance accuracy is expected to be at a level higher than chance. The importance of visual information in spelling performance suggests that (a) reading exercises that include the target words be considered an integral part of spelling instruction, and (b) attention should be directed to ambiguities, especially in the middles of words, since it is a demonstrated fact that spelling patterns in the medial positions are not normally noticed in detail in reading.

2. With respect to homophones, the model justifies and explains the practice of asking a child to make up sentences using homophonic pairs or triads. This practice serves to identify a word as a member of a homophone set and to provide contexts for distinguishing among the possible spelling patterns.

3. The practice of having children pronounce words in syllables and in exaggerated fashion is justified by the limited capacity of short-term memory and, if this model is correct, by the fact that processing is done syllable by syllable.

4. Instruction in the use of widely applicable rules and mnemonics and in the strategy of looking for lexically related words can help students resolve ambiguities, provided exceptions are also noted, by marking or flagging relevant words or syllables as requiring special attention in spelling.

5. Two possible exceptions to the prescription for emphasis on the reading vocabulary may be noted. (a) Some words are made up entirely of phonemes that are overwhelmingly frequently represented by a single spelling option--most of the consonants and short vowels. Others are made up of such phonemes plus morphs that are well established as visual or motor

representations. (b) A very limited number of rules of spelling have something like universal utility in resolving ambiguities. In these two kinds of situations, it may be possible to test mastery of sound-symbol correspondences or of certain rules by dictating nonsense words. In general, it would be an uneconomical use of student time to devote much attention to the spellings of words that meet these conditions.

6. Insistence on proofreading and the encouragement to practice generating alternate spellings in case of doubt are justified by the model as well as by empirical evidence as means of improving spelling performance.

Conclusion

We have described a method of analyzing a standard school task in terms of a hypothetical program for accomplishing it. This method of analysis makes clear the information and the processes that are required to perform the task; it points the way to the development of individual performance models, and it suggests relevant instructional strategies.

A good task analysis can help both teacher and curriculum designer answer important questions: After a child has received this instruction in this way, what can we expect him to know and be able to do that he did not know or could not do before? What will this test on these words tell us about the child's knowledge and processing strategies so that we can help him improve his performance?

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