DOCUMENT RESUME

ED 063 295 TE 002 914

AUTHOR	Simon, Dorothea P.; Simon, Herbert A.
TITLE	Alternative Uses of Phonemic Information in Spelling.
INSTITUTION	Pittsburgh Univ., Pa. Learning Research and Development Center.
SPONS AGENCY	National Inst. of Mental Health, Rockville, Md.; Office of Education (DHEW), Washington, D.C.
REPORT NO	Proj-50253
PUB DATE	72
NOTE	35p.
EDRS PRICE	MF-$0.65 HC-$3.29
DESCRIPTORS	Algorithms; Elementary School Students; Graphemes; Intonation; Memory; Oral Expression; *Phonemics; *Phonetic Analysis; Reading Improvement; Response Mode; *Spelling; *Spelling Instruction; Structural Grammar
IDENTIFIERS	Generator Test Process; Hanna Rudorf Algorithm

ABSTRACT

This paper distinguishes several ways in which phonemic information might be employed in spelling; examines some empirical data on the consequences of using these information sources; formulates hypotheses about the underlying processes involved; and suggests possible implications for the teaching (and learning) of spelling. Included are tables of the phoneme code with graphemic options and examples, Comparisons of Spelling by Elementary School Pupils with the Hanna-Rudorf Algorithm, and figures depicting the spelling and reading errors by means of a Generator-Test Process. The simulation technique discussed may be used to identify the spelling processes used by individual children and the information they hold in memory, and to diagnose and prescribe treatment for individual spelling problems. (Author/LS)

OE NCERD TE 5-0253

LEARNING RESEARCH AND DEVELOPMENT CENTER

1972/3

ALTERNATIVE USES OF PHONEMIC INFORMATION IN SPELLING

DOROTHEA P. SIMON AND HERBERT A. SIMON

Alternative Uses of Phonemic Information in Spelling

Dorothea P. Simon

Learning Research and Development Center
University of Pittsburgh

and

Herbert A. Simon

Carnegie-Mellon University

1972

The research reported herein was supported by a grant from the National Science Foundation (NSF-GJ540X-1) and by the Learning Research and Development Center, supported in part as a research and development center by funds from the United States Office of Education, Department of Health, Education, and Welfare; and by the Department of Psychology, Carnegie-Mellon University under a grant from the National Institute of Mental Health (MH-07722). The opinions expressed in this publication do not necessarily reflect the position or policy of the sponsoring agencies and no official endorsement should be inferred.

Alternative Uses of Phonemic Information in Spelling

The well-known and frequently lamented idiosyncracies of English spelling raise serious doubts as to the role that information about the spellings of individual phonemes can play in learning to spell correctly. The purpose of this paper is to distinguish several different ways in which phonemic information might be employed in spelling, to examine some empirical data on the consequences of using these different information sources, to formulate hypotheses about the underlying processes involved, and to suggest possible implications for the teaching (and learning) of spelling.

Spelling Processes--Phonemic and Other

As a framework for examining empirical data about spelling, the next paragraphs will examine a number of different kinds of information which, if stored in memory, could be used to assist the spelling process, and will propose a number of alternative spelling processes that draw on these sources of information. We will have a particular interest in phonemic information, its uses and its limitations.

Homonyms

The existence of numerous homonyms (e.g., MANE, MAIN) in English places an upper bound on the adequacy of phonemic information for indicating correct spelling. Since the members of a homonym set are, by definition, phonemically identical, the correct spelling cannot be inferred from the sound, but must be obtained from contextual information indicating meanings. Thus, in a context of lions, MANE can often be inferred; while a context of streets (or oceans) clues us to MAIN. We may sketch the spelling process in such cases by the diagram:

pronunciation + context ⟶ meaning ⟶ spelling

The arrow, in this and following diagrams, denotes an inference that may be derived from a stored direct association, or by a complicated reasoning process. In the example above, the second arrow may denote a simple association stored in long term memory, while the first arrow may denote a somewhat more complex process. We will postulate the detail of these processes only to the extent that it can reasonably be inferred from empirical evidence.

Phonemic Associations

Most persons who have learned to read have acquired some kind of associations between particular phonemes and spellings that represent them. Notice that these associations can run in either of two directions:

phoneme ⟶ spelling

spelling ⟶ phoneme

Learning the association in one direction does not necessarily cause it to be learned in the opposite direction. If such associations are used as aids in reading, it is presumably the second association that is wanted and that is learned in the sounding-out method. It is presumably the first association, however, that is wanted if phonemic information is to aid spelling. The significance of the "presumably's" will become clear as we proceed.

In neither direction, in English, is the association unambiguous. Thus, if the speller learns that a particular phoneme calls for a particular spelling, and uses that belief to spell, he will spell "phonetically" but often incorrectly.

If a speller knows that a particular phoneme may have several spellings, there are two further possibilities. On the one hand, he may simply have stored with the phoneme a list of possible spellings, ordered, say, by the frequency with which each spelling represents that phoneme. On the other hand, he may have stored in association with the phoneme a differentiated set of spellings--that is to say, an explicit or implicit set of rules that select one or another of the alternative spellings as a function of the phonemic context. We may distinguish these two possibilities by the diagrams:

$$\underline{\text{phoneme}} \longrightarrow \underline{sp_1}, \underline{sp_2}, \underline{sp_3}, \text{etc.}$$

$$\underline{\text{phoneme}} + (\underline{\text{phonemic context}})_i \longrightarrow \underline{sp_i}$$

With the first of these two forms of information storage, phonemic information can be used either to spell phonetically (e.g., by choosing in each case the first spelling on the list of alternatives), or to generate possible spellings, from which the final choice is to be made by some subsequent selection process. We shall be much concerned in this paper with the use of phoneme-letter associations as generators of possible spellings.

The second form of information storage diagrammed above has been studied extensively as a possible basis for teaching and learning English spelling. The work of Hanna and his associates sets some upper bounds on what can be expected from this process. We next summarize this evidence briefly.

Phonemic Rules

Hanna, Hanna, Hodges, and Rudorf (1966) have proposed that children be taught phonemic rules that would enable them, in most instances, to choose the correct spellings for words they have heard. They have set down a list of some 200 rules, and Rudorf (1965) has used a computer program to determine for what percentage of common words these rules would produce correct spellings.

The results are not very encouraging. A speller who used the 200 rules consistently would spell about 80 percent of all phonemes correctly, but since words contain several phonemes, this level of phonemic accuracy would allow him to spell correctly only about one-half (49.87 percent) of the 17,009 most common English words. As we shall see, most children are able to spell at a much higher level of accuracy by the time they leave high school. Hence it is not clear that the 200 rules, even if they were learned thoroughly enough to be applied consistently, would help much. However, we shall examine the evidence on this point more carefully in a later section of this paper.

Recognition and Recall

To understand spelling processes, we need to remind ourselves of the fundamental distinction in memory phenomena between recognition and recall. In order to recall a stimulus, we need complete information about the characteristics of that stimulus, else we could not reproduce it. In order to recognize the stimulus, we need only sufficient information about its characteristics to enable us to distinguish it from other stimuli that are possible in that context. In the extreme case, the context alone is enough. (What word other than "years" will satisfy for American readers the context: "Four score and seven . . . ago, our fathers brought forth . . . ."?)

As we are all aware from personal experience, the correctness or incorrectness of a spelling may be recognized in situations where we cannot recall the correct spelling. We may then hit upon the correct spelling by a trial-and-error procedure--generate alternative possible spellings, then test if they are recognized when written out.

Notice that this trial-and-error process has its precise counterpart in a procedure for sounding out words while reading--generate alternative possible phonemes to correspond to the letters of the printed word, then test if the phoneme string, when pronounced, is recognized as a familiar word. The spelling scheme suggested above assumes that information for recognizing a written word can be evoked by presenting the written word or an approximation to it, while the sounding-out scheme assumes that information for recognizing a spoken word can be evoked by the spoken word or an approximation to it. The two processes are diagrammed in Figure 1.

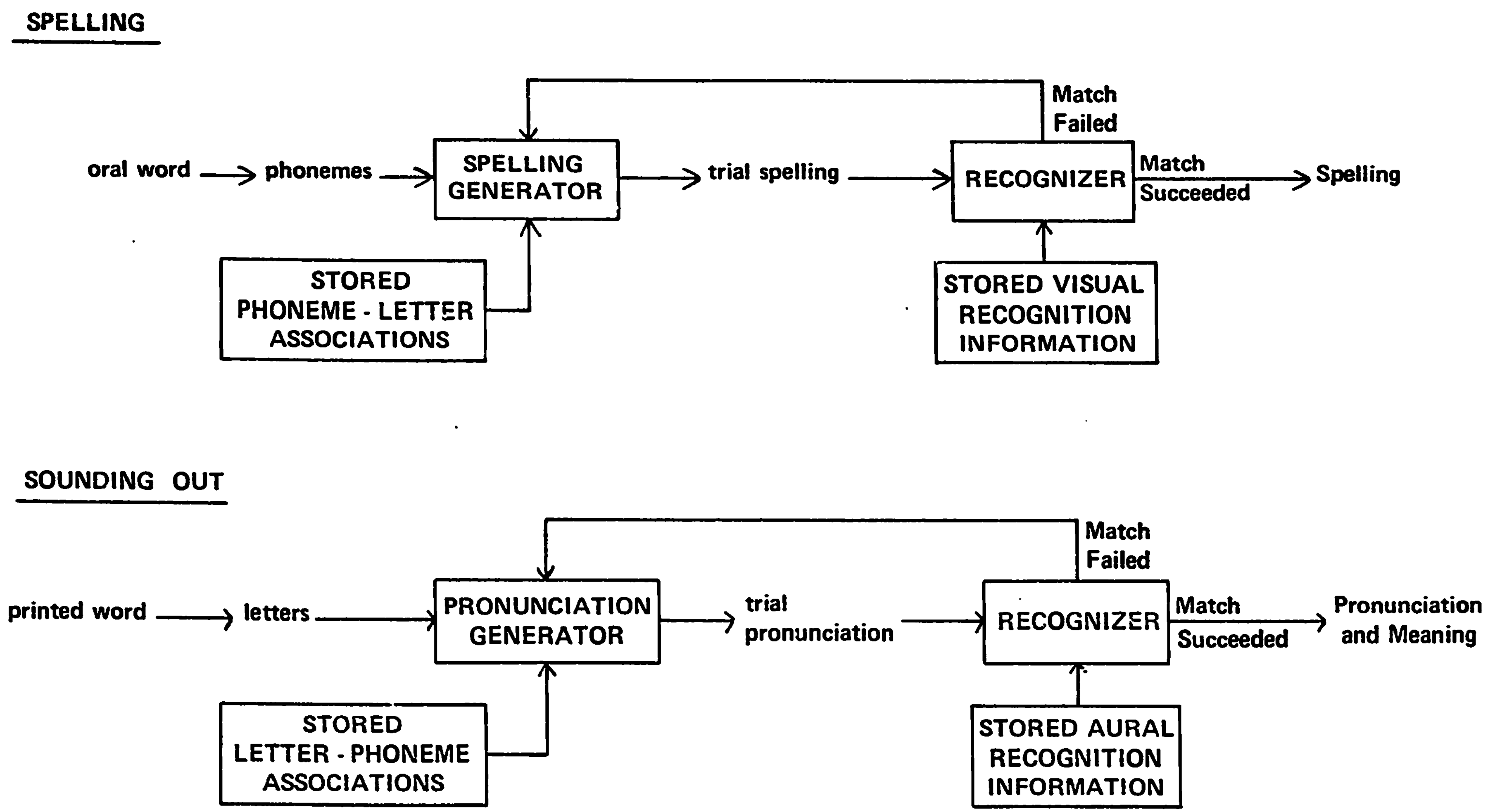
Notice also that the information used in these processes is stored at two distinct levels of aggregation--for the generators, at the level of individual phonemes and letters (and correspondences between them) and for the recognizers, at the level of whole aural and printed words (and correspondences between them). Thus the information used to generate the trial spellings and trial pronunciations is stored in the form of phoneme-letter and letter-phoneme associations, respectively, while the recognition information, used to test the proposed spellings or pronunciations, is stored as structures of information for whole words. Thus, to use the sounding-out method, the printed word must be decoded letter by letter, recoded phoneme by phoneme, but recognized at the level of the whole word. To use the trial spelling method, the aural word must be decoded phoneme by phoneme, recoded letter by letter, but recognized at the level of the whole word.

Spelling Processes

From what has already been said, it can be seen that there are a number of alternative routes along which the spelling of a particular word can be recalled. Each route requires different forms of information storage in long term memory and different processes for using the information.

1. The simplest spelling route is direct recall of the spelling of the word, associated in long term memory with its pronunciation and meaning (the latter essential because of homonyms). Probably most persons spell most words that are highly familiar to them by this process.

Figure 1: Spelling (above) and Reading (below) by Means of a Generator-Test Process



2. Two quite different routes that have been mentioned above make primary use of phonemic information rather than direct association at the word level. The first of these is direct phonemic spelling, based on stored phoneme-letter associations, supplemented to a greater or lesser extent by rules that specify the conditions under which particular spellings are to be used with particular phonemes.

3. The second phonemic route is the generate-and-test process that was described in the last section--a generator of possible spellings, based on stored phoneme-letter associations combined with a recognizer of trial spellings, based on the stored information that is used in visual word recognition. As was pointed out above, this route is exactly analogous--with the roles of phonemes and letters interchanged--to the sounding-out process in reading.

4. Each of these routes may be modified by introduction of morphemic information. (See C. Chomsky (1970) for a particular version of this idea.) Here auditory recognition of morphemic components of words gives access to spelling information (of any of the forms described above) about these components, which may be used to derive the spelling of the words containing the components. This process may also make use of conditional rules (e.g., "When adding ED or ING, double a final consonant preceded by a short vowel.").

Each of these possible spelling processes has obvious advantages and disadvantages that make it impossible, a priori, to predict which is the most advantageous and most easily learned. Direct recall requires the rote learning of thousands of spellings. Unless these are overlearned and actually used from time to time they may be forgotten relatively rapidly.

Direct phonemic spelling, without conditional rules, can produce spelling of only very low accuracy. Even when phonetic associations are supplemented by several hundred conditional rules--whose learning to a sufficient level of accessibility is itself a large task--the level of accuracy will not be acceptable.

The generate-and-test process, by itself, will not produce accurate spelling because the visual recognition information it uses to correct the phonetic generator is incomplete information. A reader need know much less than the full spelling of a word in order to recognize that word visually--and particularly in context. On the other hand, the generate-and-test process (like the sounding-out process in reading) has the greatest attractiveness in that it enables the speller to draw upon a vast store of information he already holds in long term memory--partial information about the spellings of all words that are in his reading vocabulary.

Little is known quantitatively about how these advantages and disadvantages of the different methods balance out. In the next section, however, we will consider computer programs that attempt to simulate two of the spelling processes described above--the rule-modified direct phonemic spelling process and the generate-and-test process. We will present some evidence that suggests strongly that most spellers make use of the generate-and-test process as an important tool in spelling. We will show that the errors made most commonly are those we would expect if that process were used, and that a computer program simulating that process makes exactly the kinds of spelling errors that we observe most frequently, while many of the errors made by the rule-table algorithm are very unlikely to be made by humans.

The Rule-Table Procedure for Spelling

By storing in a computer memory the appropriate information and processes, we can simulate any one of the spelling processes that has been described above--or any combination of them. For most purposes, it will be satisfactory to simplify matters by presenting the spoken word as an encoded sequence of phonemes: thus KNOWLEDGE may be represented as /N0/ /O3/ /L0/ /E3/ /J0/. Different speakers may produce different phoneme sequences for the same word, and different hearers may decode the same sound stream into different phoneme sequences, but we will ignore such variations as a first approximation. (See our discussion below (page 19) of sources of spelling irregularity.) A simplified phonemic scheme for English which has proved satisfactory for the generate-and-test program is shown in Table 1. This is a slight modification of the scheme that is used by Hanna et al. (1966) and Rudorf (1965) in their work.

The important difference between direct phonemic spelling which makes use of conditional rules and the generate-and-test process for spelling phonetically can be seen by comparing the computer programs that implement these two processes, respectively.

The Rule-Table Algorithm

The program used by Rudorf (1965) to simulate phonetic spelling with conditional rules is based on a rule table associated with each phoneme. The rule table for a given phoneme lists a number of different spellings for the phoneme, and states the conditions under which each of the spellings is to be used. The conditions may include the position of the phoneme in the word (e.g., initial, medial, syllable-final, word-final), the degree of accent, and the surrounding phonemes (e.g., "preceded by /O7/," "followed by /T1/"). The relatively simple rule table (five rules) for /U2/ (the "u" in "urn") can be paraphrased:

> (1) If initial, spell EA; (2) if preceded by /W0/, spell O; (3) if preceded by /CH0/ /B0/ or /K0/, spell U; (4) if preceded by /T1/ /G0/ /HW/ or /KW/, spell I; (5) in all other cases, spell E.

Table 1

Phoneme Code

Coded Form Phoneme	Graphemic Options	Example
A0	A-E AI AY A EIGH	ALE
A2	A AI A-E	CARE
A3	A A-E	ADD
A5	A A-E EA	ARM
E0	E EE EA E-E I-E IE	EVE
E2	E EA EE E-E IE	HERE
E3	E EA A E-E	END
E5	E U O A I	MAKER
E7	A O I E OU U	ABOUT-(SCHWA)
I0	I-E I Y IGH IE Y-E	ICE
I3	I Y I-E A-E	ILL
O0	O O-E OA OW OU	OLD
O2	O AU AW O-E OUGH	ORB, SOFT
O3	O A O-E	ODD
O6	OO O U-E OU EW UE	FOOD
O7	OO U CU O U-E	FOOT
U0	U-E U EW EU UE	UNITE
U3	U O OU O-E U-E	UP
O8	IO OY	OIL
O9	OU OW OUGH	OUT
B0	B BB	BUT
D0	D DD LD	DAY
F0	F PH FF LF GH	FILL
G0	G GG X GUE	GO
H0	H WH DG	HAT
J0	GE J DG DGE D DJ GI	JOKE
K0	C K CK CH X CC	KEEP
L0	L LL	LATE
M0	M MM MB LM	MAN
N0	N NN KN GN	NOD
P0	P PP	PEN
R0	R RR WR	RAT
S0	S C SS CE CI SC X	SIT
T0	T TT ED BT	TO
V0	V LV F VE	VAN
W0	W U	WIN
Y0	I Y	YET
Z0	S Z ES X ZZ SS	ZONE
C1	CH T TCH TI	CHAIR
W1	WH	WHAT
K1	CS CC X	BOX
L1	LE EL	TABLE
M1	M	CHASM
N1	EN ON IN	LISTEN
N2	NG N	SING
S1	TI SH CI SSI SI C CH T S	SHE
T1	TH	THIN
T2	TH	THEN
Z1	S Z ES X ZZ SS SI G Z TI	AZURE
H1	H	HONEST
K2	QU	QUILT

Performance of the Algorithm

As was mentioned earlier, the complete algorithm contains about 200 rules, and spells about one out of every two common words correctly. We present here several kinds of empirical evidence that enable us to judge the utility of the algorithm for improving spelling.

Masters (1927) gathered data on 268 words that occur within the first 5,000 of A Basic Writing Vocabulary and that had been found by Asbaugh to be misspelled by 40 percent or more of the eighth-grade pupils he tested. Of these words, 249 were attempted by the Rudorf (1965) program. It spelled correctly only 65, or about 26 percent. Yet Masters showed that generally 80 percent or more of twelfth-grade pupils spelled any one of these words correctly--not only the one in four words spelled correctly by the algorithm, but also the three in four that it missed. Clearly, these pupils were drawing on stored information far more accurate and complete than that provided by the algorithm, and there is no indication that knowledge of the algorithm would improve their spelling.

Comparison with Fourth-Grade Pupils

To provide a more concrete illustration of the problems and limitations of spelling by rule, let us compare in detail the performance of the Rudorf (1965) algorithm with the actual performance of 50 pupils beginning a fourth-grade spelling course. The pupils themselves ranged from second through fifth grade and had been pursuing a program of individualized instruction in spelling. Table 2 compares the spellings by pupils and algorithm, respectively, on the 30 words in the first two spelling lessons of the fourth-grade book, four review words, and 14 supplementary words that were presumably relevant to other courses. The student scores and spellings are taken from a pretest given to the students before they had studied the words (except the review words).

Table 2

Comparison of Spellings by Elementary School Pupils and by Hanna-Rudorf Algorithm

Word	Students (N = 50) Errors	Common Error	Algorithm Error	Spelling	Grade for 80% Correct*
bag	0				5
wet	1				5
hid	4	hide			8
log	1				5
yet	3				5
bit	8	bite	x	bate	7
bus	0		x	buss	5
desk	3				5
pond	7	pound			6
tent	0				5
flat	1				5
held	4	hald			7
slid	4	slide			8+
spot	2				5
slip	0				6
tie	1		x	ty	6
ear	2				4
deep	6	deap			5
feel	11	feal	x	feal	7
laid	25	layed, lade	x	lade	8+
team	4	teem	x	teem	5
free	1				-
goat	2				5
coal	9	cool	x	cole	6
sweet	6	sweat	x	sweat	6
mean	4	meen			5
east	0				5
feast	4	feest, fest			7
dream	6				5
asleep	3	asleap			6
Review Words					
drank	0				-
drunk	4	dronk			6
wait	13	wate	x	wate	7
afraid	8	afriad	x	afrade	8+
Supplementary Words					
add	0		x	ad	4
addend	16	adden	x	adend	-
addition	41	addion, addtion	x	adition	8
plus	3	pluse	x	pluss	7
sum	5	some**			6
column	47	colum, colem	x	colum	8+
total	32	totel, totle			7
island	12	iland	x	iland	7
delta	11				-
gulf	18	golf**			8
bay	0				5
coast	18	cost	x	cost	7
dike	11	diek, dick			-
canal	27	canel, cannal	x	conal	8

* Lowest grade at which at least 80% of the children spelled the word correctly. From the New Iowa Spelling Scale (Greene, 1954).

** In these two cases the erroneous spellings are homonyms.

On the 30 new words, the 50 children made a total of 126 errors, an average of 2.5 per child, or 8.4 percent of all the spellings. On the same words, the algorithm made eight errors in 30 words--26.6 percent. On the four review words, the children made 25 errors--12.5 percent; while the algorithm made two errors--50 percent. On the 14 supplementary words, the children made 241 errors--34.4 percent; the algorithm made eight errors--53.3 percent. In all three classes of words, the algorithm made far more errors than the average child. Thus, when we examine words thought appropriate for the spelling vocabularies of fourth-grade students, we find that the students spell the words better than the algorithm even before they have studied them explicitly.

The same words that were misspelled by the algorithm tended to be difficult for the children. On the list of new words, only "bit," "pond," "deep," "feel," "laid," "coal," "sweet," and "dream," eight words in all, were misspelled by more than ten percent of the children. Five of these eight words were also misspelled by the algorithm, together with three words ("bus," "tie," and "team") that were spelled correctly by more than 90 percent of the children. In the case of three of the "difficult" words and one of the "easy" words misspelled by the algorithm, the erroneous spelling was identical with the most common, or one of the most common, spellings of the children who missed that word ("feal" for "feel"; "lade" for "laid"; "teem" for "team"; and "sweat" for "sweet"). The same thing may be said of four of the frequently misspelled review and supplementary words: "wate" for "wait"; "colum" for "column"; "iland" for "island"; "cost" for "coast." In two cases ("sum" and "gulf") some of the children chose the wrong homonym, while the algorithm was luckier.

In the final column of Table 2, we show, from Masters' (1927) data, the grade level by which 80 percent or more of all students can be expected to spell each word correctly. The single fourth-grade word on the list was misspelled by the algorithm, as were two of the 16 fifth-grade words and three of the eight sixth-grade words. These are words the students might be expected to acquire soon, with or without the algorithm. Could the algorithm help, however, with the harder words? Hardly. It misspelled six of nine seventh-grade words, two of four eighth-grade words, and three of four words on which mastery was not achieved by 80 percent of the students by the eighth grade.

Performance on Difficult Words

In his list of 268 difficult common words, Masters (1927) discovered 117 which, when misspelled, were misspelled in a relatively consistent way. That is, a single form accounted for more than half of the misspellings of each of these 117 words. We can compare 51 of these words, their spellings and typical misspellings, with the spellings produced by the algorithm. (The remaining 66, mostly inflected forms, are not in the list that the algorithm spelled.)

The algorithm spelled only 15--less than one-third--of the 51 words correctly. In eight cases, its misspelling was identical with the typical human misspelling, and in nine other cases, algorithm and humans shared at least one error in common. In the remaining 19 cases, the errors made by the algorithm were different from the typical human errors. The words, together with the typical misspellings and the algorithm's spellings, are shown in Table 3.

Even this small sample of words gives a good picture of the nature of typical human spelling errors. In nearly all cases, the typical misspelling implicates a single phoneme. Eighteen misspellings--more than one-third--involve a schwa (at least in some pronunciations of the word); eight involve other vowels; nine involve the choice between single and

Table 3

Misspellings of "Hard Words" by Hanna-Rudorf Algorithm and by Typical Students

Word	Rudorf Algorithm (Blank if Correct)	Equal (=) or Similar (∿)	Typical Misspelling*
consistent			consistant
convenient	conveanient		convient
correspondence	corespondence		correspondance
curiosity			curiousity
decidedly	desidedly		dicidely
deem	deam	=	deam
delegate			deligate
despair	despare		dispair
disappoint	disapoint	∿	dissapoint
disappointment	disapointment	∿	dissapointment
divine	davine		devine
dormitory			dormatory
duly			duely
edition			addition
efficiency	efitionsy		effeciency
existence			existance
exquisite	exquisate		exquisit
fascinate	fasanate	∿	facinate
fundamental			fundemental
genius	geanious		genious
grateful			greatful
imitation			immitation
inconvenience	inconveanience		inconvience
indefinite	indefanate	∿	indefinate
infinite	infanate	∿	infinate
innocent	inosunt	∿	inocent
kindergarten			kindergarden
laboratory	laboritory		labratory
mortgage	morgage	=	morgage
mysterious	misterious	=	misterious
mystery	mistery	=	mistery
perceive	perseive		percieve
possess	pasess	∿	posess
procedure	prosegure		proceedure
psychology	sicology		Psychology
questionnaire	questieounaire		questionaire
rating	rateing	=	rateing
receiver	reseiever		reciever
reckon	recen	∿	recon
recommend	recomend		reccommend
recommendation	recomendation	=	recomendation
remembrance			rememberance
ridiculous			rediculous
romantic			romatic
seize	seas		sieze
specimen	spesamen		speciman
spiritual			spirtual
thorough	thiro		through
temporary	temporery		temperary
tonnage	tunage	∿	tonage
virtue	vertue	=	vertue
visible	visable	=	visable

* Masters (1927), 30-32.

doubled consonants; three are consonantal errors of other kinds; nine involve homonyms or incorrect inferences from morphemes; and four involve miscellaneous difficulties. Hence, mistaken phonetic spellings predominate, and most of the remaining errors can be described as due to incorrect use of morphemic or semantic information. This is the same picture that emerges from Masters' (1927) analysis of his whole list of 268 words (see pages 71-74 of his monograph), and from the words from fourth-grade spelling lists shown in Table 2. The evidence from all of these sources is completely consistent.

Alternative Phonetic-Morphemic Schemes

The question may be asked whether the right phonetic rules were used in the Hanna-Rudorf scheme. In particular, N. Chomsky and M. Halle (1968) have proposed that English possesses a deep phonetic structure that is more closely related to orthography than is the surface structure. (For a brief discussion of their theory and its implications for spelling, see C. Chomsky, 1970.) Thus, for example, the lexical item, PRESIDE (/P0/ /R0/ /E0/ /Z0/ /I0/ /D0/) disambiguates the spelling of PRESIDENT, where a surface phonetic variation has changed the long vowel, /I0/, to the schwa, /E7/.

It has been suggested (Chomsky, 1970, pp. 304-305) that the greater correspondence of orthography to phonetic deep structure can be used in teaching spelling. Thus, if the speller learned to generate several words having the same lexical base, these might help him resolve ambiguities. In the example above, the schwa in PRESIDENT would not be misspelled if the derivation from PRESIDE were noticed.

There are two difficulties with this proposal. First, it can lead to wrong spellings, e.g., ABSTAINENCE for ABSTINENCE. Second, it applies to relatively few words. We have not determined systematically how many words misspelled by the Hanna-Rudorf algorithm could be handled by attention to phonetic deep structure, but examination of Tables 2 and 3 suggests that there are relatively few. In Table 2, the double D in ADDEND and ADDITION could be inferred by anyone who could spell ADD (which the Hanna-Rudorf algorithm could not). TOTAL, which the algorithm spelled correctly, could also be inferred, perhaps, from TOTALITY. In Table 3, LABORATORY (from LABOR), provides a positive instance, as does SPIRITUAL (SPIRIT), and perhaps the single C and double MM in RECOMMEND (RE+COMMEND). On the other hand, the missing E in REMEMBRANCE shows how the procedure can lead the speller astray (as does the missing E in PROCEDURE!).

We conclude that the Chomsky proposal might have some use in building a spelling program, but probably can play only a quite minor role.

Conclusions

What conclusions can be drawn from these data? We must be careful to distinguish between conclusions about the specific spelling algorithm used by Rudorf, on the one hand, and conclusions about phonetic information in general. As far as the algorithm is concerned, the evidence is decisive that ability to use it would not help fourth-grade children to spell many of the words they do not already know how to spell (or can guess how to spell). On the totality of "new words" that the algorithm could spell--22 words--the children averaged only 1.2 errors per child. Hence, at best, the algorithm could only have improved spelling by five percent, even if its systematic use did not introduce errors in words that children had previously spelled correctly. Similarly, the algorithm spelled correctly only 15 of the 51 "hard" words we examined, and even these 51 words are spelled correctly by most college students

(80 percent or more in 43 cases, 90 percent or more in 24 cases). Hence, at this more advanced level also, consistent use of the algorithm would degrade the spelling of all but the poorest human spellers.

In a sense, we have been burning a straw man. No persons, certainly not the Hannas and their associates, have proposed using a spelling algorithm as the core or sole basis of spelling instruction. We discuss these matters in detail, however, because the results of the studies of phonetic regularity in spelling have been variously interpreted by the proponents and critics of phonetic approaches to spelling. The facts adduced by both proponents and opponents show consistently that a reasonably sophisticated algorithm can be expected to spell about 80 percent of phonemes and 50 percent of words correctly. These facts do not justify reliance on the algorithm, per se. We will have to consider further, however, what they imply in general for uses of phonemic information.

It is important for our discussion that, with relatively few exceptions, the spelling errors made by humans (see Tables 2 and 3) do not reveal any reluctance on their part to use phonemic cues. On the contrary, most of their errors, like the algorithm's, were made on words that are spelled in a phonetically ambiguous or irregular way.

Generate-and-Test Phonetic Processes

If phonemic information is not to be learned and applied in the form of an algorithm, how then can it be used at all? We have already discussed one alternative possibility--to use such information to generate possible spellings, these to be tested or screened with the aid of visual recognition information. Before elaborating on this process, and considering its practicality, we need to underscore an important distinction between two kinds of phonetic irregularities in spelling.

Sources of Spelling Irregularity

A spelling may be phonetically irregular when (1) it is ambiguous, or (2) it is non-phonetic. A spelling is ambiguous if one or more of its phonemes can be represented by several different letter combinations. The typical offender here is the schwa, which on different occasions can be represented by A, E, I, O, or U, to say nothing of more exotic combinations of these. A spelling is non-phonetic if one or more of its letters bear little or no relation to the phonemes. The S in "island" is a characteristic example.

Whether a spelling is non-phonetic is relative to the list of readings that is admitted for each of the phonemes. For example, by admitting "SL" as a (rare) reading for /L0/, we can even regularize "island." Likewise, the K in "know" can be viewed as a non-phonetic element, or the readings for /N0/ can be expanded to include KN. Since the KN reading for /N0/ is much more common than the SL reading for /L0/, we are likely to regard the former but not the latter as phonetic. Observe that when a spelling is "phoneticized" by expanding the list of admissible readings for a phoneme, new ambiguity is introduced, for now the speller must choose between the alternative readings of the phoneme.

Ambiguity is also relative, and falls in several categories. First, a spelling may be ambiguous because pronunciation varies with dialect or with the degree of care exercised by the speaker. Different phonemic renderings of the word may then yield different spellings.

Second, even if a word is always pronounced in the same way, its spelling may be ambiguous because some of its phonemes have multiple admissible readings. This is also a relative matter (and not only because we may regularize irregularities as shown above), for by introducing conditions we may distinguish among the situations in which one or another reading is to be used, and hence, reduce the ambiguity, e.g., "I before E except after C." This is the route taken by the algorithm, and the source of its 200 rules.

Non-Deterministic Algorithms

The Rudorf spelling algorithm eliminates ambiguity entirely. That is to say, it proposes a specific spelling for every word presented to it. But it accomplishes this at the cost of spelling many words (half of them!) incorrectly. This suggests the possibility of reducing the conditionality of the algorithm, but retaining the alternate readings--that is, of making the algorithm non-deterministic. (Non-deterministic algorithms have theoretical and practical importance in several areas of computer science.)

A non-deterministic spelling algorithm will not propose a unique spelling for a word, but will propose one or more spellings for each of the phonemes in the word. There are several ways to make a definite choice among the alternatives that are proposed. One way--the simplest--is always to choose the first alternative. To have a name for it, we may call this procedure "pure phonetic spelling." Another way is to follow the generation of alternatives with a selection process to choose among them. We will examine this method in a moment.

Observe that conditionality in the spelling of a phoneme need not be absent from a non-deterministic spelling algorithm. We can retain as many of the conditional rules as we like, leaving the indeterminacy only where the employment of additional conditions would appear to introduce more errors than it eliminates. Thus, we might retain the distinction between initial and other positions in the spelling of /NO/, and allow KN on the list of admissible readings only for the initial position. (In fact, the Rudorf (1965; Hanna et al., 1966) algorithm does not allow the KN reading in any position--a consequent source of error that can be removed by making the algorithm non-deterministic.)

Thus, we can, in a certain sense, both have and eat our cake. We can have as much of the sophistication as we wish of a conditional algorithm, combined with as much of the flexibility as we wish of a non-deterministic algorithm. We can have a conditional, non-deterministic algorithm, and if we wish to do so, we can afford to make it even more conditional if it is non-deterministic than if it is deterministic.

The non-deterministic algorithm is also helpful in dealing with ambiguities due to variant pronunciation. We can handle these either by reducing the list of phonemes, combining similar phonemes into a single one (e.g., representing by a single phoneme the /E/ of "maker" and the /U/ of "urn," or the /L/ of "late" and the /L/ of "able"), or by enlarging the list of admissible readings for each phoneme, or by some combination of these two methods.

Word-Recognition Information

We will now make these ideas more concrete by describing a specific spelling algorithm which uses a non-deterministic phonetic component to generate possible spellings of phonemes and a body of word-recognition information to test the correctness of proposed spellings. It will be argued, after this non-deterministic algorithm has been described, that its procedures are similar to those used by human spellers for words whose direct spellings they do not know, and that it can serve as a model for designing programs of spelling instruction. A particular, very simple, version of the algorithm, which we have named SPEL, has been written in the SNOBOL (sic!) programming language. We will present examples of its behavior below.

By word-recognition information we mean information stored in memory that enables a reader to recognize a word when it is presented to him visually. Even out of context, a word may be REC.G.Z.BLE when only a fraction of its letters are presented. When it is presented in context, as in the example of the previous sentence, it may be R.........L. with even less information.

We can think of a reader's word-recognition information as stored in his memory in association with a kind of sorting net. When a word is presented visually, it is sorted down the net, which serves as an index to the memory, until the partial image of the word is found. A sorting net of this kind is at the core of the EPAM (Feigenbaum, 1961; Simon & Feigenbaum, 1964) theory of verbal learning, which has had considerable success in explaining a variety of phenomena from verbal learning experiments. An important feature of this kind of memory organization when applied to word recognition is that the information in the image can be retrieved only on presentation of an appropriate visual stimulus--that is, of the appropriate word perhaps not quite correctly spelled.

Hence, the word-recognition information that a reader gradually accumulates with experience is available only in an indirect way to help him spell. If he can produce a spelling close enough to the correct one so that he can recognize the word in question, he can then retrieve, by recognition, such information about its form as is stored in memory. (It is not argued that this is the only information that spellers use. As was suggested earlier, they may also have stored in memory direct associations from the spoken word and its meaning to the letter sequence; it is this latter, direct, information that is undoubtedly used to spell highly overlearned words. And they may also have stored some rule information to use as a mnemonic in some cases.)

By drawing on his word-recognition information, in combination with his phonetic knowledge, a child can use his growing reading vocabulary to bootstrap his spelling competence. As has been often suggested, most correct spelling is probably learned by a combination of phonetics with reading. An important piece of evidence in support of this hypothesis is the fact that relatively few spelling errors on words within the reading vocabulary involve the first two or three letters--letters that are almost always a part of the word-recognition information that has been stored (see Kooi, Schutz, & Baker, 1965).

<u>Description of the SPEL Algorithm</u>

The algorithm is given two inputs: (1) a list of the phoneme sequence for a word, and (2) a list providing the hypothesized word-recognition knowledge available for that word. For example, the phoneme list for "knowledge" might be "N0 O3 L0 E3 J0" and the recognition list, "K N -". The latter list is to be interpreted as "a K followed by an N followed by (any) other letters." The word-recognition information is to be considered as part of the contents of long term memory. The algorithm also has stored in its long term memory a list of readings for each phoneme. For example, with the phoneme /N0/ may be stored the list "N NN KN." At present, these lists are unconditional, but conditions could be introduced into them in a more sophisticated form of the program.

When instructed to spell a word, after presentation of the phoneme list and recognition list, SPEL takes up each phoneme in sequence and seeks a spelling for it that is consistent with the recognition list. If it exhausts the list of readings for a particular phoneme without finding one that matches, it backs up and changes readings assigned earlier. If it encounters a "-", it seeks to match the letter, if any, that follows with one of the unused phonemes, and interpolates, ahead of the matching one, the first readings of each of the unused phonemes.

Consider the example of "knowledge," with the recognition information given above: K N -. The readings of N and NN for /N0/ (see Table 1) are rejected for failure to match the initial K and KN is accepted.

The algorithm finds the "-", but no specific letters beyond, hence adopts the first readings of each of the remaining phonemes: O for /O3/, L for /L0/, E for /E3/, GE for /J0/. Hence, it spells "knowledge" as KNOLEGE.

Any of the inputs to the algorithm--the phoneme list, the recognition list, or the lists of phoneme readings--can be altered to see what effect this would have on the spelling of the word. Thus, if the order of the /J0/ list were changed to put the reading J first, the spelling of "knowledge" would change to KNOLEJ. If the second vowel in "knowledge" were interpreted as the schwa (encoded as /E7/), with the initial list of readings, the spelling would become KNOLAGE. If the recognition list were expanded to "K N - D G E," the spelling would be KNOLEDGE. In this case, the D beyond the dash would be matched by one reading of /J0/, (DGE), and the OLE filled in. If the recognition list were blank, "-", the word would be spelled entirely phonetically--i.e., by using the first reading on each phoneme reading list--with a resultant spelling like NOLEJ, say.

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 what readings have already been tried. The substance of the algorithm involves nothing more than what has already been outlined. Nevertheless, what we have called "programming details" may not be without psychological significance. Any child who undertook to use a procedure like this to test out possible spellings would also have to keep track of his matching process and of the alternatives he had already generated. The presence of the programming details will help remind us, therefore, that learning to use such a procedure to help spelling may be a non-trivial task.

Comparison of SPEL with Children's Spelling

Suppose that a speller were using this generate-and-test process--phonemic associations to generate possible spellings, visual recognition information to check them. What kinds of spelling errors would we expect him to make? Since we know that the initial and final groups of letters in a word are the most important, and generally most used, for recognition, we would expect him to make relatively few errors on those letters, and many more on letters in the middle (see Kooi et al., 1965; Feigenbaum & Simon, 1962). We might postulate something like the typical serial position curve to predict the relative frequencies of errors as a function of position within the word.

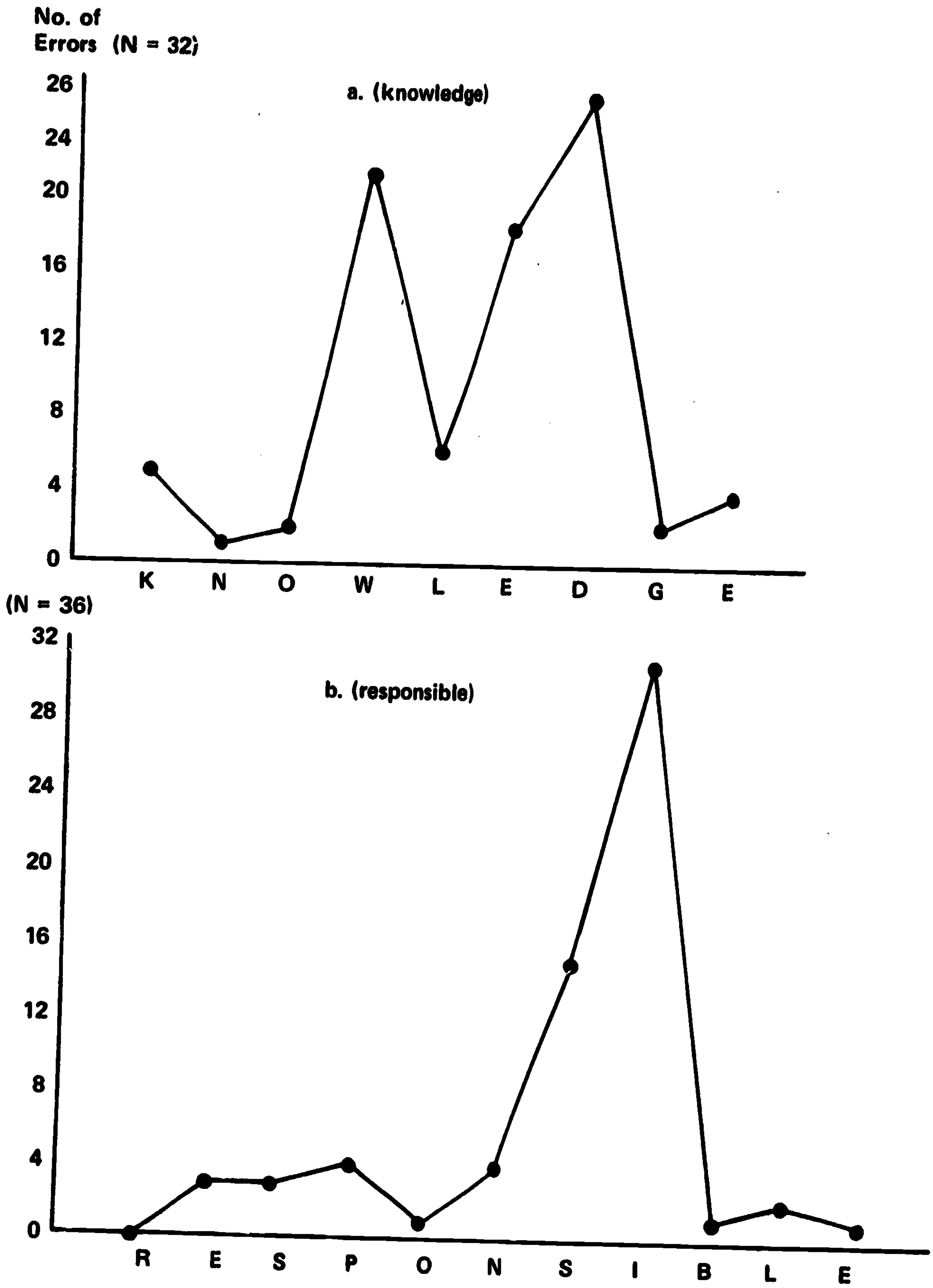
On the other hand, if phonemic associations alone are being used to generate possible spellings, many more errors will be made with ambiguous phonemes, those with many alternative spellings (e.g., the schwa or /S/), than with the phonemes that have few alternative spellings (e.g., /B/ or /D/). Suppose we had a predictive measure of the contributions of these two factors--position in word and phonemic ambiguity--to the probability of a misspelling of a phoneme. To take the simplest model, let p_{in} be the average probability that a phoneme in the i^{th} position of an n-letter word will be misspelled; and let a_k be proportional to the average probability that the most common spelling of phoneme k will be an incorrect spelling in any particular instance. Then if the i^{th} phoneme in a particular n-letter word is phoneme k, and assuming independence of the two probabilities, we would predict that it will be misspelled with probability $e_{in,k} = p_{in} \cdot a_k$.

Consider, for example, the word "knowledge." Assume that the recognition list for that word is something like "KNO...GE" for most subjects. Then few errors will be made on the first three and last two letters (p_{in} will be close to zero for these); but many will be made on those remaining letters for which the ambiguity, a_k, is high (for these letters p_{in} will be close to unity). Three of the missing letters correspond to ambiguous phonemes (W from the /O3/, E from the schwa, and D from the /J0/), hence have large a_k; while the remaining letter, L, corresponds to a relatively unambiguous phoneme, /L0/, hence has small a_k. Therefore, we would predict that most of the errors in spelling "knowledge" would involve the W, E, and D; and that we would find frequently such spellings as KNOWLEGE, KNOLEGE, KNOLAGE, and so on.

Spellers with even less recognition information about the word would spread their errors over more of the phonemes. In particular, spellers whose reading vocabularies did not include "knowledge" might be expected to produce such attempts as NOLEJ, NOLEGE, NAHLEJE, NOLAGE, and other exotic combinations. But while these combinations may be "exotic," they are not random. It is easy to see how they come about.

These expectations are not disappointed when we look at the data from 47 fourth-graders who had attempted to spell "knowledge." About one-third, 15, produced the correct spelling. Of the remainder, 26 correctly transcribed /N0/ as KN, and five transcribed it as N. Only one produced a non-phonetic transcription, KL. Apart from the correct spelling, the most common ones were KNOWLEGE, with the D omitted, and KNOWLAGE, with the D omitted and an A for the schwa. Of the 32 erroneous spellings, only 10 can be regarded as genuinely non-phonetic. These involved such errors as interchange of W and L (3 cases), W and O, G and D. Figure 2 shows the serial positions of the errors made by these 32 pupils. They lie exactly where we expected them--few errors in K, N, or O; many in W, but few in L; many in E and D; few in G and E. (See Figure 2.)

Figure 2: Distribution of Spelling Errors*
Grade 4 Children



*Errors were scored as follows: Children's spellings were transcribed onto a matrix of which columns were the correct letters, rows were individual misspellings; letters that were present and in correct order were entered in the appropriate column; one error was scored for each omission, substitution of single letter, or substitution of multi-letter phonemic option.

These kinds of results are readily reproduced by the simulation program. Table 4 summarizes the results of a number of runs. The first column shows the phonetic list for "knowledge," the second, the word recognition list, and the third, the spelling produced. With completely phonetic spelling (blank recognition list), we get the spelling NOLAGE or NOLAJ, depending on whether the admissible spellings of /J0/ are listed in the order (GE, J, ...) or (J, GE, ...). Substituting /E3/ for the schwa as the fourth phoneme, we get NOLEGE or NOLEJ, respectively. If, now, the recognition information, "KN-" is supplied, we get KNOLAGE, KNOLAJ, KNOLEGE, and KNOLEJ, respectively. If the recognition information is expanded to "KN-GE," only the forms ending in GE are produced. To obtain the correct spelling would require recognition information at least as complete as "KN-W-DGE." The 26 pupils who wrote the KNOW correctly may have used morphemic information--that "knowledge" is derived from "know." Eight children had the KNOW but not the D, while only one who wrote DGE missed KNOW.

We have carried out a similar analysis for the spelling by these 47 pupils of the word "responsible." In this case, only eleven spelled the word correctly, and the vast bulk of the errors was concentrated on the schwa (a total of 31 errors for the spelling of this phoneme). As Table 5 shows, the most likely misspelling, as indicated by the simulation, is RESPONSABLE. This was the most popular misspelling, produced by 11 pupils. The other phoneme accounting for many errors, seven in all, is the ambiguous /S0/ preceding the schwa. Pupils represented this by S, CE, TS, and C, all of which can be produced by the algorithm by simple permutation of the list of readings for this phoneme. Five additional misspellings were phonetic; the remaining 13 largely involved the omission of transcriptions for one or more phonemes (e.g., REPOSABLE). These latter errors cannot be explained by our theory or

Table 4

Performance of Algorithm on "knowledge"

Phonetic List	Recognition List	Spelling
/N0 O3 L0 E7 J0/	"-"	NOLAJ
"	"-"	NOLAGE*
/N0 O3 L0 E3 J0/	"-"	NOLEJ
"	"-"	NOLEGE*
"	"KN-"	KNOLEGE*
"	"KNOW-GE"	KNOWLEGE
"	"KN-W-DGE"	KNOWLEDGE

* Readings for /J0/ changed from (J, GE, ...) to (GE, J, ...)

Table 5

Performance of Algorithm on "responsible"

Phonetic List	Recognition List	Spelling
/R0 E3 S0 P0 O3 N0 S0 E7 B0 L1/	"-"	RESPONSABLE
"	"-"	RESPANSABLE*
"	"-"	RESPONCEABLE**
/R0 E3 S0 P0 O3 N0 S0 E7 B0 L0/	"-"	RESPONSABL
/R0 E3 S0 P0 O3 N0 S0 E7 B0 L1/	"RESPON-BLE"	RESPONSABLE
"	"R-IBLE"	RESPONSIBLE

* Readings for /O3/ changed from (O, A, ...) to (A, O, ...)
** Readings for /S0/ changed from (S, ...) to (CE, ...)

produced by the simulation program. The others can be produced by permutations of the lists of admissible readings, or by varying the amounts of recognition knowledge provided. Table 5 gives examples.

By now the reader will see readily how the simulation program can be modified by simple changes and permutations of lists to produce such popular misspellings by these same 47 children of other words as FURTILIZER (4), FERTELIZER (2), and FERTALIZER (2), but not quite FERTERLIZER (4); ACOMADATE (6) and ACCOMODATE (3); OCASION (5) and OCCATION (2); ELAVATOR (6); SPECTATER (9); GRAMMER (19) and GRAMER (13).

From these data, which are completely consistent with the other information we have about common misspellings, we can conclude that a large part of the spelling behavior of fourth-graders can be explained on the hypothesis that they use a phonetic generator combined with a recognition test in order to spell words of which they are not entirely sure. When the recognition information is insufficient to rule out phonetically correct, even though erroneous, spellings, the pupils use precisely those spellings. A large part of the individual differences among students can be attributed to small differences in the completeness of their recognition knowledge, differences in their pronunciation--or phonetic rendition--of the words, and differences in the content and ordering of their lists of admissible readings for each phoneme.

Conclusions and Implications

While the theory of spelling proposed here has a great deal of empirical support, one should be cautious in drawing from it conclusions about what are the effective ways to teach spelling. The data and theory give no encouragement to the idea that pupils should learn sophisticated schemes or rules for phoneme transcription. Most of the errors that pupils make are not errors that can be corrected by the application of phonemic information. Instead, what is largely lacking is sufficient visual information about spelling--either in the form of direct associations or in the form of recognition information--to filter out the errors caused by phonetic ambiguity.

The kind of phonetic experience that would appear to be most valuable to pupils is experience in generating possible alternative transcriptions for testing by recognition. This experience can be given without requiring pupils to learn complex systems of rules, since what is wanted are lists for each phoneme, and not unique transcriptions. The pupil can be encouraged to behave like a non-deterministic algorithm! And this requires much less complex learning from him than would be required to behave like an algorithm containing deterministic phonetic rules.

At the same time, spelling will only be learned if sufficient visual recognition information is also available. A considerable part of this information is normally acquired as a by-product of growing a reading vocabulary. Hence, by restricting spelling practice to words within the children's reading vocabularies, this information becomes available automatically to the generate-and-test process.

Words can be recognized, however, without full information about their spelling. Consideration should be given to techniques for getting children to attend to parts of words not normally used in recognition--particularly the central parts. Discussion of specific ways of doing this is beyond the scope of this paper, but several such techniques are described and used in some of the standard spelling books.

It may turn out to be effective to make students explicitly aware of the generate-and-test technique for spelling, and to encourage them to try out alternatives rather than to arrive immediately at the "one correct spelling." It would be highly desirable to have some empirical research aimed at testing the utility of such procedures.

Finally, we have focused on "typical" spelling errors, and have said little about individual differences. As every teacher knows, the spelling errors of a minority of students are mainly non-phonetic in nature. There is no reason to suppose that the techniques that are best adapted to the majority of phonetically oriented students are also well adapted to this minority. The simulation technique discussed in this paper holds some promise as a technique for identifying the spelling processes used by individual children and the information they hold in memory, and as a basis for diagnosing and prescribing treatment for individual spelling problems. Again, this promise will only be realized if the technique is subjected to further empirical research.

The debate over the past decade or two on the utility of using phonic approaches in the teaching of spelling has no doubt led to the introduction of some innovative techniques in spelling instruction. However, the question of whether "phonics" should be taught as a part of the teaching of spelling is much too broad and vague. In this paper, we have explored two main alternative processes for using phonemic information in spelling. Undoubtedly there are others. It is quite as important--perhaps more important--to learn how to introduce phonemic information, and to learn how the speller can best use it, as it is to learn whether to use phonemic information. It is time we turned from the latter question to the former, and designed research to answer it.

References

Chomsky, C. Reading, writing, and phonology, Harvard Educational Review, 1970, Vol. 40, No. 2, 287-309.

Chomsky, N., & Halle, M. The Sound Pattern of English. (New York: Harper & Row, 1968.)

Feigenbaum, E. A. The simulation of verbal learning behavior, Proceedings of Western Joint Computer Conference, 1961, 121-132.

Feigenbaum, E. A., & Simon, H. A. A theory of the serial position effect, British Journal of Psychology, 1962, Vol. 53, 307-320.

Greene, H. A. The New Iowa Spelling Scale. (Iowa City: State University of Iowa, 1954.)

Hanna, P. R., Hanna, J. S., Hodges, R. E., & Rudorf, E. H., Jr. Phoneme-Grapheme Correspondences as Cues to Spelling Improvement. (Washington, D. C.: U. S. Government Printing Office, 1966.)

Kooi, B. Y., Schutz, R. D., & Baker, R. L. Spelling errors and the serial position effect, Journal of Educational Psychology, 1965, Vol. 56, No. 6, 334-336.

Masters, H. V. A Study of Spelling Errors. (Iowa City: University of Iowa Studies in Education, Vol. IV, No. 4, 1st Series #138, September 1, 1927.)

Rudorf, E. H., Jr. "The Development of an Algorithm for American-English Spelling," Ph. D. dissertation, Stanford University, 1965. (Published on demand by University Microfilms, Inc., Ann Arbor, Michigan.)

Simon, H. A., & Feigenbaum, E. A. An information-processing theory of some effects of similarity, familiarization, and meaningfulness in verbal learning, Journal of Verbal Learning and Verbal Behavior, 1964, Vol. 3, 385-396.