and state governments may properly have an interest in cooperating with the local authorities.

The best program in the world can fail in the face of opposition or apathy on the part of the public. The commission report calls upon the public to undertake three tasks: (i) to become familiar with information about air conservation and air pollution, calling upon the scientific community and the government for assistance; (ii) to consider the problems of all segments of the community: industries, utilities, and private citizens; (iii) to urge, permit, and require the appropriate governments (federal, state, and local) to take actions necessary to ensure that the air of the areas within their respective jurisdictions is of the quality desired by the people of those areas, and that the quality is maintained.

A Challenge and an Opportunity

Man has been wasteful of the resources of the world in which he lives. He has ravaged its forests and soils and has plundered its mineral wealth; he has squandered and soiled its waters; he has contaminated its air. No reasonable person would suggest that man not use his environment, or that he revert to his primitive past. But no reasonable person can condone his wasteful excesses.

The problem of air pollution very probably will never be "solved." But if man is willing to recognize it as a problem, if he is prepared to bring to the problem his political wisdom, his scientific knowledge, and his technological skills, if he is willing to work with nature instead of against it, then he can leave to his children and his children's children something more valuable and more necessary to human life than any of the manufactured products of his civilization. He can bequeath to them the blessing of clean air.

Learning to Read

Experimental psychologists examine the process by which a fundamental intellectual skill is acquired.

Eleanor J. Gibson

Educators and the public have exhibited a keen interest in the teaching of reading ever since free public education became a fact (*1*). Either because of or despite their interest, this most important subject has been remarkably susceptible to the influence of fads and fashions and curiously unaffected by disciplined experimental and theoretical psychology. The psychologists have traditionally pursued the study of verbal learning by means of experiments with nonsense syllables and the like—that is, materials carefully divested of useful information. And the educators, who found little in this work that seemed relevant to the classroom, have stayed with the classroom; when they performed experiments, the method was apt to be a gross comparison of classes privileged and unprivileged with respect to the latest fad. The result has been two cultures: the pure scientists in the laboratory, and the practical teachers ignorant of the progress that has been made in the theory of human learning and in methods of studying it.

That this split was unfortunate is clear enough. True, most children do learn to read. But some learn to read badly, so that school systems must provide remedial clinics; and a small proportion (but still a large number of future citizens) remain functional illiterates. The fashions which have led to classroom experiments, such as the "whole word" method, emphasis on context and pictures for "meaning," the "flash" method, "speed reading," revised alphabets, the "return" to "phonics," and so on, have done little to change the situation.

Yet a systematic approach to the understanding of reading skill is possible. The psychologist has only to treat reading as a learning problem, to apply ingenuity in theory construction and experimental design to this fundamental activity on which the rest of man's education depends. A beginning has recently been made in this direction, and it can be expected that a number of theoretical and experimental studies of reading will be forthcoming (*2*).

Analysis of the Reading Process

A prerequisite to good research on reading is a psychological analysis of the reading process. What is it that a skilled reader has learned? Knowing this (or having a pretty good idea of it), one may consider how the skill is learned, and next how it could best be taught. Hypotheses designed to answer all three of these questions can then be tested by experiment.

There are several ways of characterizing the behavior we call reading. It is receiving communication; it is making discriminative responses to graphic symbols; it is decoding graphic symbols to speech; and it is getting meaning from the printed page. A child in the early stages of acquiring reading skill may not be doing all these things, however. Some aspects of reading must be mastered before others and have an essential function in a sequence of development of the final skill. The average child, when he begins learning to read, has already mastered to a marvelous extent the art of communication. He can speak and understand his own language in a fairly complex way, employing units of language organized in a hierarchy and with a grammatical structure. Since a writing system must correspond to the spoken one, and since speech is prior to writing, the frame-

The author is senior research associate in psychology at Cornell University. This article is adapted from a paper read at a conference on Perceptual and Linguistic Aspects of Reading, sponsored by the Committee on Learning and the Educational Process of the Social Science Research Council and held at the Center for Advanced Study in the Behavioral Sciences, Palo Alto, California, 31 October 1963.

work and unit structure of speech will determine more or less the structure of the writing system, though the rules of correspondence vary for different languages and writing systems. Some alphabetic writing systems have nearly perfect single-letter-to-sound correspondences, but some, like English, have far more complex correspondence between spelling patterns and speech patterns. Whatever the nature of the correspondences, it is vital to a proper analysis of the reading task that they be understood. And it is vital to remember, as well, that the first stage in the child's mastery of reading is learning to communicate by means of spoken language.

Once a child begins his progression from spoken language to written language, there are, I think, three phases of learning to be considered. They present three different kinds of learning tasks, and they are roughly sequential, though there must be considerable overlapping. These three phases are: learning to differentiate graphic symbols; learning to decode letters to sounds ("map" the letters into sounds); and using progressively higher-order units of structure. I shall consider these three stages in order and in some detail and describe experiments exploring each stage.

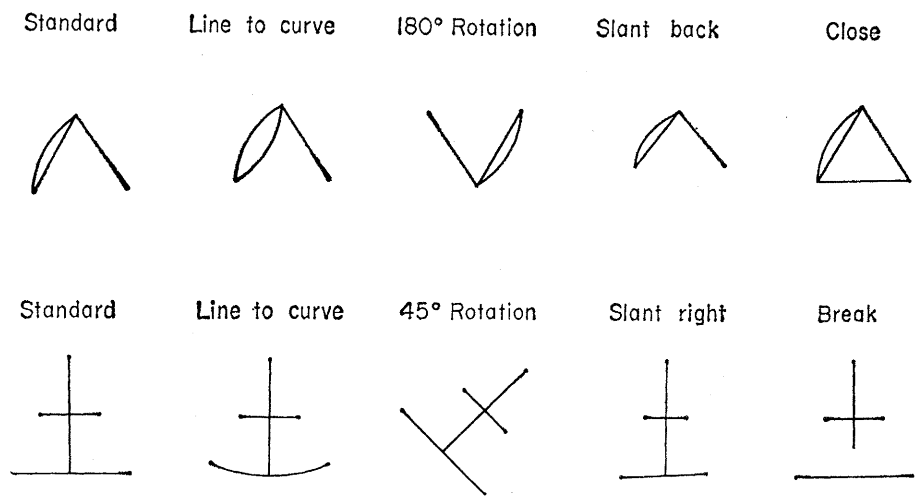

Fig. 1. Examples of letter-like figures illustrating different types of transformation.

Differentiation of Written Symbols

Making any discriminative response to printed characters is considered by some a kind of reading. A very young child, or even a monkey, can be taught to point to a patch of yellow color, rather than a patch of blue, when the printed characters YELLOW are presented. Various people, in recent popular publications, have seriously suggested teaching infants to respond discriminatively in this way to letter patterns, implying that this is teaching them to "read." Such responses are not reading, however; reading entails decoding to speech. Letters are, essentially, an instruction to produce a given speech sound.

Nevertheless, differentiation of written characters from one another is a logically preliminary stage to decoding them to speech. The learning problem is one of discriminating and recognizing a set of line figures, all very similar in a number of ways (for example, all are tracings on paper) and each differing from all the others in one or more features (as straight versus curved). The differentiating features must remain invariant under certain transformations (size, brightness, and perspective transformations and less easily described ones produced by different type faces and handwriting). They must therefore be relational, so that these transformations will not destroy them.

It might be questioned whether learning is necessary for these figures to be discriminated from one another. This question has been investigated by Gibson, Gibson, Pick, and Osser (*3*). In order to trace the development of letter differentiation as it is related to those features of letters which are critical for the task, we designed specified transformations for each of a group of standard, artificial letter-like forms comparable to printed Roman capitals. Variants were constructed from each standard figure to yield the following 12 transformations for each one: three degrees of transformation from line to curve; five transformations of rotation or reversal; two perspective transformations; and two topological transformations (see Fig. 1 for examples). All of these except the perspective transformations we considered critical for discriminating letters. For example, contrast V and U; C and U; O and C.

The discrimination task required the subject to match a standard figure against all of its transformations and some copies of it and to select only identical copies. An error score (the number of times an item that was not an identical copy was selected) was obtained for each child, and the errors were classified according to the type of transformation. The subjects were children aged 4 through 8 years. As would be expected, the visual discrimination of these letter-like forms improved from age 4 to age 8, but the slopes of the error curves were different, depending on the transformation to be discriminated (Fig. 2). In other words, some transformations are harder to discriminate than others, and improvement occurs at different rates for different transformations. Even the youngest subjects made relatively few errors involving changes of break or close, and among the 8-year-olds these errors dropped to zero. Errors for perspective transformations were very numerous among 4-year-olds and still numerous among 8-year-olds. Errors for rotations and reversals started high but dropped to nearly zero by 8 years. Errors for changes from line to curve were relatively numerous (depending on the number of changes) among the youngest children and showed a rapid drop among the older—almost to zero for the 8-year-olds.

The experiment was replicated with the same transformations of real letters on the 5-year-old group. The correlation between confusions of the same transformations for real letters and for the letter-like forms was very high ($r = +.87$), so the effect of a given transformation has generality (is not specific to a given form).

What happens, in the years from 4 to 8, to produce or hamper improvement in discrimination? Our results suggest that the children have learned the features or dimensions of difference which are critical for differentiating letters. Some differences are critical, such as break versus close, line versus curve, and rotations and reversals; but some, such as the perspective transformations, are not, and must

Table 1. Number of errors made in transfer stage by groups with three types of training.

Group	Type of training		Errors
	Standards	Transformations	
E1	Same	Different	69
E2	Different	Same	39
C	Different	Different	101

in fact be tolerated. The child of 4 does not start "cold" upon this task, because some of his previous experience with distinctive features of objects and pictures will transfer to letter differentiation. But the set of letters has a unique feature pattern for each of its members, so learning of the distinctive features goes on during the period we investigated.

If this interpretation is correct, it would be useful to know just what the distinctive features of letters are. What dimensions of difference must a child learn to detect in order to perceive each letter as unique? Gibson, Osser, Schiff, and Smith *(4)* investigated this question. Our method was to draw up a chart of the features of a given set of letters *(5)*, test to see which of these letters were most frequently confused by prereading children, and compare the errors in the resulting "confusion matrix" with those predicted by the feature chart.

A set of distinctive features for letters must be relational in the sense that each feature presents a contrast which is invariant under certain transformations, and it must yield a unique pattern for each letter. The set must

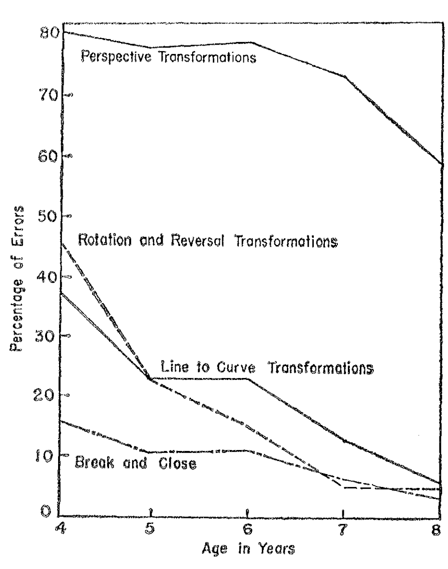

Fig. 2. Error curves showing rate of improvement in discriminating four types of transformation.

also be reasonably economical. Two feature lists which satisfy these requirements for a specified type face were tried out against the results of a confusion matrix obtained with the same type (simplified Roman capitals available on a sign-typewriter).

Each of the features in the list in Fig. 3 is or is not a characteristic of each of the 26 letters. Regarding each letter one asks, for example, "Is there a curved segment?" and gets a yes or no answer. A filled-in feature chart gives a unique pattern for each letter. However, the number of potential features for letter-shapes is very large, and would vary from one alphabet and type font to another. Whether or not we have the right set can be tested with a confusion matrix. Children should confuse with greatest frequency the letters having the smallest number of feature differences, if the features have been chosen correctly.

We obtained our confusion matrix from 4-year-old children, who made matching judgments of letters, programmed so that every letter had an equal opportunity to be mistaken for any other, without bias from order effects. The "percent feature difference" for any two letters was determined by dividing the total number of features possessed by either letter, but not both, by the total number possessed by both, whether shared or not. Correlations were then calculated between percent feature difference and number of confusions, one for each letter. The feature list of Fig. 3 yielded 12 out of 26 positive significant correlations. Prediction from this feature list is fairly good, in view of the fact that features were not weighted. A multidimensional analysis of the matrix corroborated the choice of the curve-straight and obliqueness variables, suggesting that these features may have priority in the discrimination process and perhaps developmentally. Refinement of the feature list will take these facts into account, and other methods of validation will be tried.

Detecting Distinctive Features

If we are correct in thinking that the child comes to discriminate graphemes by detecting their distinctive features, what is the learning process like? That it is perceptual learning and need not be verbalized is probable (though teachers do often call attention to contrasts between letter shapes.) An experiment by Anne D. Pick *(6)* was designed to compare two hypotheses about how this type of discrimination develops. One might be called a "schema" or "prototype" hypothesis, and is based on the supposition that the child builds up a kind of model or memory image of each letter by repeated experience of visual presentations of the letter; perceptual theories which propose that discrimination occurs by matching sensory experience to a previously stored concept or categorical model are of this kind. In the other hypothesis it is assumed that the child learns by discovering how the forms differ, and then easily transfers this knowledge to new letter-like figures.

Pick employed a transfer design in which subjects were presented in step 1 with initially confusable stimuli (letter-like forms) and trained to discriminate between them. For step 2 (the transfer stage) the subjects were divided into three groups. One experimental group was given sets of stimuli to discriminate which varied in new dimensions from the *same standards* discriminated in stage 1. A second experimental group was given sets of stimuli which deviated from *new standards*, but in the same dimensions of difference discriminated in stage 1. A control group was given both new standards and new dimensions of difference to discriminate in stage 2. Better performance by the first experimental group would suggest that discrimination learning proceeded by construction of a model or memory image of the standards against which the variants could be matched. Conversely, better performance by the second experimental group would suggest that dimensions of difference had been detected.

The subjects were kindergarten children. The stimuli were letter-like forms of the type described earlier. There were six standard forms and six transformations of each of them. The transformations consisted of two changes of line to curve, a right-left reversal, a 45-degree rotation, a perspective transformation, and a size transformation. Table 1 gives the errors of discrimination for all three groups in stage 2. Both experimental groups performed significantly better than the control group, but the group that had familiar transformations of new standards performed significantly better than the group given new transformations of old standards.

We infer from these results that, while children probably do learn prototypes of letter shapes, the prototypes themselves are not the original basis for differentiation. The most relevant kind of training for discrimination is practice which provides experience with the characteristic differences that distinguish the set of items. Features which are actually distinctive for letters could be emphasized by presenting letters in contrast pairs.

Features	A	B	C	E	K	L	N	U	X	Z
Straight segment										
Horizontal	+			+		+				+
Vertical		+		+	+	+	+			
Oblique /	+				+				+	+
Oblique \	+				+		+		+	
Curve										
Closed		+								
Open vertically								+		
Open horizontally			+							
Intersection	+	+		+	+				+	
Redundancy										
Cyclic change		+		+						
Symmetry	+	+	+	+	+			+	+	
Discontinuity										
Vertical	+				+				+	
Horizontal				+		+	+			+

Fig. 3. Example of a "feature chart." Whether the features chosen are actually effective for discriminating letters must be determined by experiment.

Decoding Letters to Sounds

When the graphemes are reasonably discriminable from one another, the decoding process becomes possible. This process, common sense and many psychologists would tell us, is simply a matter of associating a graphic stimulus with the appropriate spoken response—that is to say, it is the traditional stimulus-response paradigm, a kind of paired-associate learning.

Obvious as this description seems, problems arise when one takes a closer look. Here are just a few. The graphic code is related to the speech code by rules of correspondence. If these rules are known, decoding of new items is predictable. Do we want to build up, one by one, automatically cued responses, or do we want to teach with transfer in mind? If we want to teach for transfer, how do we do it? Should the child be aware that this is a code game with rules? Or will induction of the rules be automatic? What units of both codes should we start with? Should we start with single letters, in the hope that knowledge of single-letter-to-sound relationships will yield the most transfer? Or should we start with whole words, in the hope that component relationships will be induced?

Carol Bishop (*7*) investigated the question of the significance of knowledge of component letter-sound relationships in reading new words. In her experiment, the child's process of learning to read was simulated by teaching adult subjects to read some Arabic words. The purpose was to determine the transfer value of training with individual letters as opposed to whole words, and to investigate the role of component letter-sound associations in transfer to learning new words.

A three-stage transfer design was employed. The letters were 12 Arabic characters, each with a one-to-one letter-sound correspondence. There were eight consonants and four vowels, which were combined to form two sets of eight Arabic words. The 12 letters appeared at least once in both sets of words. A native speaker of the language recorded on tape the 12 letter-sounds and the two sets of words. The graphic form of each letter or word was printed on a card.

The subjects were divided into three groups—the letter training group (L), the whole-word training group (W), and a control group (C). Stage 1 of the experiment was identical for all groups. The subjects learned to pronounce the set of words (transfer set) which would appear in stage 3 by listening to the recording and repeating the words. Stage 2 varied. Group L listened to and repeated the 12 letter-sounds and then learned to associate the individual graphic shapes with their correct sounds. Group W followed the same procedure, except that eight words were given them to learn, rather than letters. Learning time was equal for the two groups. Group C spent the same time-interval on an unrelated task. Stage 3 was the same for the three groups. All subjects learned to read the set of words they had heard in stage 1, responding to the presentation of a word on a card by pronouncing it. This was the transfer stage on which the three groups were compared.

At the close of stage 3, all subjects were tested on their ability to give the correct letter-sound following the presentation of each printed letter. They were asked afterward to explain how they tried to learn the transfer words.

Figure 4 shows that learning took place in fewest trials for the letter group and next fewest for the word group. That is, letter training had more transfer value than word training, but word training did produce some transfer. The subjects of group L also knew, on the average, a greater number of component letter-sound correspondences, but some subjects in group W had learned all 12. Most of the subjects in group L reported that they had tried to learn by using knowledge of component correspondences. But so did 12 of the 20 subjects in group W, and the scores of these 12 subjects on the transfer task were similar to those of the letter-trained group. The subjects who had learned by whole words and had not used individual correspondences performed no better on the task than the control subjects.

It is possible, then, to learn to read words without learning the component letter-sound correspondences. But transfer to new words depends on use of them, whatever the method of original training. Word training was as good as letter training if the subject had analyzed for himself the component relationships.

Learning Variable and Constant Component Correspondences

In Bishop's experiment, the component letter-sound relationships were regular and consistent. It has often been pointed out, especially by advocates of spelling reform and revised alphabets (*8*), that in English this is

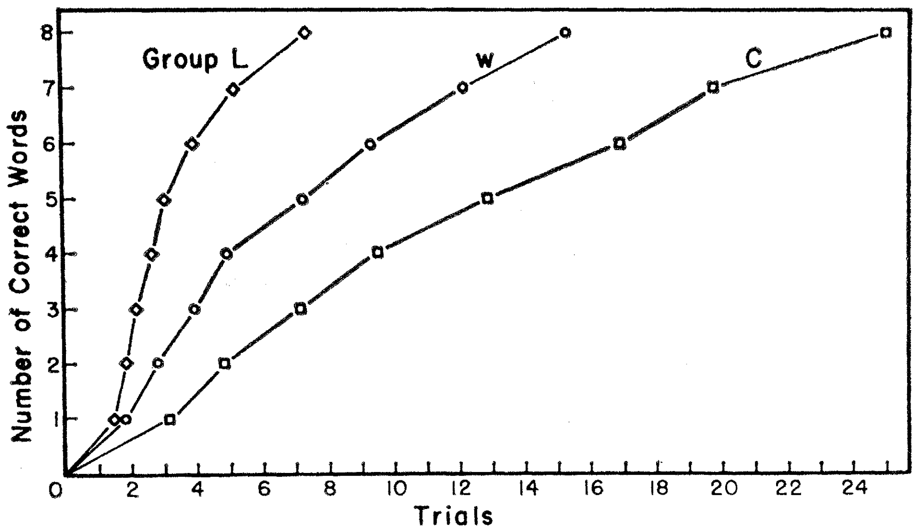

Fig. 4. Learning curves on transfer task for group trained originally with whole words (W), group trained with single letters (L), and control group (C).

not the case. Bloomfield (*9*) suggested that the beginning reader should, therefore, be presented with material carefully programmed for teaching those orthographic-phonic regularities which exist in English, and should be introduced later and only gradually to the complexities of English spelling and to the fact that single-letter-to-sound relationships are often variable. But actually, there has been no hard evidence to suggest that transfer, later, to reading spelling-patterns with more variable component correspondence will be facilitated by beginning with only constant ones. Although variable ones may be harder to learn in the beginning, the original difficulty may be compensated for by facilitating later learning.

A series of experiments directed by Harry Levin (*10*) dealt with the effect of learning variable as opposed to constant letter-sound relationships, on transfer to learning new letter-sound relationships. In one experiment, the learning material was short lists of paired-associates, with a word written in artificial characters as stimulus and a triphoneme familiar English word as response. Subjects (third-grade children) in one group were given a list which contained constant graph-to-sound relationships (one-to-one component correspondence) followed by a list in which this correspondence was variable with respect to the medial vowel sound. Another group started with a similarly constructed variable list and followed it with a second one. The group that learned lists with a variable component in both stages was superior to the other group in the second stage. The results suggest that initiating the task with a variable list created an expectation of learning set for variability of correspondence which was transferred to the second list and facilitated learning it.

In a second experiment, the constant or variable graph-sound relation occurred on the first letter. Again, the group with original variable training performed better on the second, variable list. In a third experiment adult native speakers of English and Spanish were compared. The artificial graphs were paired with nonsense words. Again there was more transfer from a variable first list to a variable second list than from a constant to a variable one. Variable lists were more difficult, on the whole, for the Spanish speakers, perhaps because their native language contains highly regular letter-sound relationships.

A "set for diversity" may, therefore, facilitate transfer to learning of new letter-sound correspondences which contain variable relationships. But many questions about how the code is learned remain to be solved, because the true units of the graphic code are not necessarily single letters. While single-letter-sound relations in English are indeed variable, at other levels of structure regularity may be discovered.

Lower- and Higher-Order Units

For many years, linguists have been concerned with the question of units in language. That language has a hierarchical structure, with units of different kinds and levels, is generally accepted, though the definition of the units is not easily reached. One criterion of a unit is recodability—consistent mapping or translation to another code. If such a criterion be granted, graphic units must parallel linguistic units. The units of the writing system should be defined, in other words, by mapping rules which link them to the speech code, at all levels of structure.

What then are the true graphic units? What levels of units are there? Exactly how are they mapped to linguistic units? In what "chunks" are they perceived? We must first try to answer these questions by a logical analysis of properties of the writing and speech systems and the correspondences between them. Then we can look at the behavior of skilled readers and see how units are processed during reading. If the logical analysis of the correspondence rules is correct, we should be able to predict what kinds of units are actually processed and to check our predictions experimentally.

Common sense suggests that the unit for reading is the single grapheme, and that the reader proceeds sequentially from left to right, letter by letter, across the page. But we can assert at once and unequivocally that this picture is false. For the English language, the single graphemes map consistently into speech only as morphemes—that is, the names of the letters of the alphabet. It is possible, of course, to name letters sequentially across a line of print ("spell out" a word), but that is not the goal of a skilled reader, nor is it what he does. Dodge (*11*) showed, nearly 60 years ago, that perception occurs in reading only during fixations, and not at all during the saccadic jumps from one fixation to the next. With a fast tachistoscopic exposure, a skilled reader can perceive four unconnected letters, a very long word, and four or more words if they form a sentence (*12*). Even first graders can read three-letter words exposed for only 40 milliseconds, too short a time for sequential eye-movements to occur.

Broadbent (*13*) has pointed out that speech, although it consists of a temporal sequence of stimuli, is responded to at the end of a sequence. That is, it is normal for a whole sequence to be delivered before a response is made. For instance, the sentence "Would you give me your ——— ?" might end with any of a large number of words, such as "name" or "wallet" or "wife." The response depends on the total message. The fact that the component stimuli for speech and reading are spread over time does not means that the phonemes or letters or words are processed one at a time, with each stimulus decoded to a separate response. The fact that O is pronounced differently in BOAT and BOMB is not a hideous peculiarity of English which must consequently be reformed. The O is read only in context and is never responded to in isolation. It is part of a sequence which contains constraints of two kinds, one morphological and the other the spelling patterns which are characteristic of English.

If any doubt remains as to the unlikelihood of sequential processing letter by letter, there is recent evidence of Newman (*14*) and of Kolers (*15*) on sequential exposure of letters. When letters forming a familiar word are exposed sequentially in the same place, it is almost impossible to read the word. With an exposure of 100 milliseconds per letter, words of six letters are read with only 20 percent probability of accuracy; and with an exposure of 375 milliseconds per letter, the probability is still well under 100 percent. But that is more than 2 seconds to perceive a short, well-known word! We can conclude that, however graphemes are processed perceptually in reading, it is not a letter-by-letter sequence of acts.

If the single grapheme does not map consistently to a phoneme, and furthermore, if perception normally takes in bigger "chunks" of graphic stimuli in a single fixation, what are the smallest graphic units consistently coded into phonemic patterns? Must they be whole words? Are there different levels of units? Are they achieved at different stages of development?

Spelling Patterns

It is my belief that the smallest component units in written English are spelling patterns (*16*). By a spelling pattern, I mean a cluster of graphemes in a given environment which has an invariant pronunciation according to the rules of English. These rules are the regularities which appear when, for instance, any vowel or consonant or cluster is shown to correspond with a given pronunciation in an initial, medial, or final position in the spelling of a word. This kind of regularity is not merely "frequency" (bigram frequency, trigram frequency, and so on), for it implies that frequency counts are relevant for establishing rules only if the right units and the right relationships are counted. The relevant graphic unit is a functional unit of one or more letters, in a given position within the word, which is in correspondence with a specified pronunciation (*17*).

If potential regularities exist within words—the spelling patterns that occur in regular correspondence with speech patterns—one may hypothesize that these correspondences have been assimilated by the skilled reader of English (whether or not he can verbalize the rules) and have the effect of organizing units for perception. It follows that strings of letters which are generated by the rules will be perceived more easily than ones which are not, even when they are unfamiliar words or not words at all.

Several experiments testing this prediction were performed by Gibson, Pick, Osser, and Hammond (*18*). The basic design was to compare the perceptibility (with a very short tachistoscopic exposure) of two sets of letter-strings, all nonsense or pseudo words, which differed in their spelling-to-sound correlation. One list, called the "pronounceable" list, contained words with a high spelling-to-sound correlation. Each of them had an initial consonant-spelling with a single, regular pronunciation; a final consonant-spelling having a single regular pronunciation; and a vowel-spelling, placed between them, having a single regular pronunciation when it follows and is followed by the given initial and final consonant spellings, respectively—for example, GL/UR/CK. The words in the second list, called the "unpronounceable" list, had a low spelling-to-sound correlation. They were constructed from the words in the first list by reversing the initial and final consonant spellings. The medial vowel spelling was not changed. For example, GLURCK became CKURGL. There were 25 such pseudo words in each list, varying in length from four to eight letters. The pronunciability of the resulting lists was validated in two ways, first by ratings, and second by obtaining the number of variations when the pseudo words were actually pronounced.

The words were projected on a screen in random order, in five successive presentations with an exposure time beginning at 50 milliseconds and progressing up to 250 milliseconds. The subjects (college students) were instructed to write each word as it was projected. The mean percentage of pronounceable words correctly perceived was consistently and significantly greater at all exposure times.

The experiment was later repeated with the same material but a different judgment. After the pseudo word was exposed, it was followed by a multiple-choice list of four items, one of the correct one and the other three the most common errors produced in the previous experiment. The subject chose the word he thought he had seen from the choice list and recorded a number (its order in the list). Again the mean of pronounceable pseudo words correctly perceived significantly exceeded that of their unpronounceable counterparts. We conclude from these experiments that skilled readers more easily perceive as a unit pseudo words which follow the rules of English spelling-to-sound correspondence; that spelling patterns which have invariant relations to sound patterns function as a unit, thus facilitating the decoding process.

In another experiment, Gibson, Osser, and Pick (*19*) studied the development of perception of grapheme-phoneme correspondences. We wanted to know how early, in learning to read, children begin to respond to spelling-patterns as units. The experiment was designed to compare children at the end of the first grade and at the end of the third grade in ability to recognize familiar three-letter words, pronounceable trigrams, and unpronounceable trigrams. The three-letter words were taken from the first-grade reading list; each word chosen could be rearranged into a meaningless but pronounceable trigram and a meaningless and unpronounceable one (for example, RAN, NAR, RNA). Some longer pseudo words (four and five letters) taken from the previous experiments were included as well. The words and pseudo words were exposed tachistoscopically to individual children, who were required to spell them orally. The first-graders read (spelled out) most accurately the familiar three-letter words, but read the pronounceable trigrams significantly better than the unpronounceable ones. The longer pseudo words were seldom read accurately and were not differentiated by pronunciability. The third-grade girls read all three-letter combinations with high and about equal accuracy, but differentiated the longer pseudo words; that is, the pronounceable four- and five-letter pseudo words were more often perceived correctly than their unpronounceable counterparts.

These results suggest that a child in the first stages of reading skill typically reads in short units, but has already generalized certain regularities of spelling-to-sound correspondence, so that three-letter pseudo words which fit the rules are more easily read as units. As skill develops, span increases, and a similar difference can be observed for longer items. The longer items involve more complex conditional rules and longer clusters, so that the generalizations must increase in complexity. The fact that a child can begin very early to perceive regularities of correspondence between the printed and spoken patterns, and transfer them to the reading of unfamiliar items as units, suggests that the opportunities for discovering the correspondences between patterns might well be enhanced in programming reading materials.

I have referred several times to *levels* of units. The last experiment showed that the size and complexity of the spelling patterns which can be perceived as units increase with development of reading skill. That other levels of structure, both syntactic and semantic, contain units as large as and larger than the word, and that perception of skilled readers will be found, in suitable experiments, to be a function of these factors is almost axiomatic. As yet we have little direct evidence better than Cattell's original discovery (*12*) that when words are structured into a sentence, more letters can be accurately perceived "at a glance." Developmental studies of perceptual "chunking" in relation to structural complexity may be very instructive.

Where does meaning come in? Within the immediate span of visual perception, meaning is less effective in structuring written material than good spelling-to-sound correspondence, as Gibson, Bishop, Schiff, and Smith (*20*) have shown. Real words which are both meaningful and, as strings of letters, structured in accordance with English spelling patterns are more easily perceived than nonword pronounceable strings of letters; but the latter are more easily perceived than meaningful but unpronounceable letter-strings (for example, BIM is perceived accurately, with tachistoscopic exposure, faster than IBM). The role of meaning in the visual perception of words probably increases as longer strings of words (more than one) are dealt with. A sentence has two kinds of constraint, semantic and syntactic, which make it intelligible (easily heard) and memorable (*21*). It is important that the child develop reading habits which utilize all the types of constraint present in the stimulus, since they constitute structure and are, therefore, unit-formers. The skills which the child should acquire in reading are habits of utilizing the constraints in letter strings (the spelling and morphemic patterns) and in word strings (the syntactic and semantic patterns). We could go on to consider still superordinate ones, perhaps, but the problem of the unit, of levels of units, and mapping rules from writing to speech has just begun to be explored with experimental techniques. Further research on the definition and processing of units should lead to new insights about the nature of reading skill and its attainment.

Summary

Reading begins with the child's acquisition of spoken language. Later he learns to differentiate the graphic symbols from one another and to decode these to familiar speech sounds. As he learns the code, he must progressively utilize the structural constraints which are built into it in order to attain the skilled performance which is characterized by processing of higher-order units —the spelling and morphological patterns of the language.

Because of my firm conviction that good pedagogy is based on a deep understanding of the discipline to be taught and the nature of the learning process involved, I have tried to show that the psychology of reading can benefit from a program of theoretical analysis and experiment. An analysis of the reading task—its discriminatory and decoding aspects as well as the semantic and syntactical aspects—tells us *what* must be learned. An analysis of the learning process tells us *how*. The consideration of formal instruction comes only after these steps, and its precepts should follow from them.

References and Notes

1. See C. C. Fries, *Linguistics and Reading* (Holt, Rinehart, and Winston, New York, 1963), for an excellent chapter on past practice and theory in the teaching of reading.
2. In 1959, Cornell University was awarded a grant for a Basic Research Project on Reading by the Cooperative Research Program of the Office of Education, U.S. Department of Health, Education, and Welfare. Most of the work reported in this article was supported by this grant. The Office of Education has recently organized "Project Literacy," which will promote research on reading in a number of laboratories, as well as encourage mutual understanding between experimentalists and teachers of reading.
3. E. J. Gibson, J. J. Gibson, A. D. Pick, H. Osser, *J. Comp. Physiol. Psychol.* **55**, 897 (1962).
4. E. J. Gibson, H. Osser, W. Schiff, J. Smith, in *A Basic Research Program on Reading*, Final Report on Cooperative Research Project No. 639 to the Office of Education, Department of Health, Education, and Welfare.
5. The method was greatly influenced by the analysis of distinctive features of phonemes by Jakobsen and M. Halle, presented in *Fundamentals of Language* (Mouton, The Hague, 1956). A table of 12 features, each in binary opposition, yields a unique pattern for all phonemes, so that any one is distinguishable from any other by its pattern of attributes. A pair of phonemes may differ by any number of features, the minimal distinction being one feature opposition. The features must be invariant under certain transformations and essentially relational, so as to remain distinctive over a wide range of speakers, intonations, and so on.
6. A. D. Pick, *J. Exp. Psychol.*, in press.
7. C. H. Bishop, *J. Verbal Learning Verbal Behav.* **3**, 215 (1964).
8. Current advocates of a revised alphabet who emphasize the low letter-sound correspondence in English are Sir James Pitman and John A. Downing. Pitman's revised alphabet, called the Initial Teaching Alphabet, consists of 43 characters, some traditional and some new. It is designed for instruction of the beginning reader, who later transfers to traditional English spelling. See I. J. Pitman, *J. Roy. Soc. Arts* **109**, 149 (1961); J. A. Downing, *Brit. J. Educ. Psychol.* **32**, 166 (1962); ——, "Experiments with Pitman's initial teaching alphabet in British schools," paper presented at the Eighth Annual Conference of International Reading Association, Miami, Fla., May 1963.
9. L. Bloomfield, *Elem. Engl. Rev.* **19**, 125, 183 (1942).
10. See research reports of H. Levin and J. Watson, and H. Levin, E. Baum, and S. Bostwick, in *A Basic Research Program on Reading* (see *4*).
11. R. Dodge, *Psychol. Bull.* **2**, 193 (1905).
12. J. McK. Cattell, *Phil. Studies* **2**, 635 (1885).
13. D. E. Broadbent, *Perception and Communication* (Pergamon, New York, 1958).
14. E. Newman, *Am. J. Psychol.*, in press.
15. P. A. Kolers and M. T. Katzman, paper presented before the Psychonomic Society, Aug. 1963, Bryn Mawr, Pa.
16. Spelling patterns in English have been discussed by C. C. Fries in *Linguistics and Reading* (Holt, Rinehart, and Winston, New York, 1963), p. 169 ff. C. F. Hockett, in *A Basic Research Program on Reading* (see *4*), has made an analysis of English graphic monosyllables which presents regularities of spelling patterns in relation to pronunciation. This study was continued by R. Venezky (thesis, Cornell Univ., 1962), who wrote a computer program for obtaining the regularities of English spelling-to-sound correspondence. The data obtained by means of the computer permit one to look up any vowel or consonant cluster of up to five letters and find its pronunciation in initial, medial, and final positions in a word. Letter environments as well have now been included in the analysis. See also R. H. Weir, *Formulation of Grapheme-Phoneme Correspondence Rules to Aid in the Teaching of Reading*, Report on Cooperative Research Project No. 5-039 to the Office of Education, Department of Health, Education and Welfare.
17. For example, the cluster GH may lawfully be pronounced as an F at the end of a word, but never at the beginning. The vowel cluster EIGH, pronounced /Ā/ (/ej/), may occur in initial, medial, and final positions, and does so with nearly equal distribution. These cases account for all but two occurrences of the cluster in English orthography. A good example of regularity influenced by environment is [c] in a medial position before I plus a vowel. It is always pronounced /S/ (*social, ancient, judicious*).
18. E. J. Gibson, A. D. Pick, H. Osser, M. Hammond, *Am. J. Psychol.* **75**, 554 (1962).
19. E. J. Gibson, H. Osser, A. D. Pick, *J. Verbal Learning Verbal Behav.* **2**, 142 (1963).
20. E. J. Gibson, C. H. Bishop, W. Schiff, J. Smith, *J. Exp. Psychol.*, **67**, 173 (1964).
21. G. A. Miller and S. Isard, *J. Verbal Learning Verbal Behav.* **2**, 217 (1963); also L. E. Marks and G. A. Miller, *ibid.* **3**, 1 (1964).