HOW PSYCHOLOGICAL SCIENCE INFORMS THE TEACHING OF READING

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Abstract—*This monograph discusses research, theory, and practice relevant to how children learn to read English. After an initial overview of writing systems, the discussion summarizes research from developmental psychology on children's language competency when they enter school and on the nature of early reading development. Subsequent sections review theories of learning to read, the characteristics of children who do not learn to read (i.e., who have developmental dyslexia), research from cognitive psychology and cognitive neuroscience on skilled reading, and connectionist models of learning to read. The implications of the research findings for learning to read and teaching reading are discussed. Next, the primary methods used to teach reading (phonics and whole language) are summarized. The final section reviews laboratory and classroom studies on teaching reading. From these different sources of evidence, two inescapable conclusions emerge: (a) Mastering the alphabetic principle (that written symbols are associated with phonemes) is essential to becoming proficient in the skill of reading, and (b) methods that teach this principle directly are more effective than those that do not (especially for children who are at risk in some way for having difficulty learning to read). Using whole-language activities to supplement phonics instruction does help make reading fun and meaningful for children, but ultimately, phonics instruction is critically important because it helps beginning readers understand the alphabetic principle and learn new words. Thus, elementary-school teachers who make the alphabetic principle explicit are most effective in helping their students become skilled, independent readers.*

INTRODUCTION

Learning to read presents a paradox. For an adult who is a good reader, reading feels so simple, effortless, and automatic that it is almost impossible to look at a word and not read it. Reading seems so natural to the literate adult that one could easily imagine that it must rank among the simplest skills for a child to acquire. Yet nothing could be further from the truth. For many children, learning to read is an extraordinarily effortful task, a long and complicated process that can last for years. That is the essence of the paradox. How can a skill that feels so easy to the adult be so difficult for the child to acquire? The paradox is interesting to the scientist because learning to read is strikingly different from other sorts of learning.

But the significance of the paradox is more general, in ways that touch everyone. Literacy is an essential ingredient of success in societies like ours, where so much information is conveyed by the written word. Furthermore, a literate population is a key to the functioning of these societies. A significant number of people never achieve the effortless literacy of the skilled reader. For them, the complex process of learning to read never came to an end. To help them, as well as children just learning to read, it is important to understand the source of their difficulty and how to overcome it. To achieve these goals, scientists need to understand three aspects of the paradox:

1. The starting point: What are the preconditions for learning to read? What must a child be able to do in order to learn to read effectively?
2. The learning process: What is the process of learning to read? What happens when a person goes from being a non-reader to being a reader?
3. The end point: What does skilled reading—the end point of the learning process—look like?

As scientists learn more about the starting point, the process, and the end point of learning to read, they can more effectively address the vital fourth issue:

4. Appropriate educational practices: What are the best ways to teach reading?

These are the central topics with which we are concerned in this monograph.

The major instructional methods traditionally used to teach reading have been *whole-word* and *phonics* instruction. In whole-word instruction (also called the *look-say* method), a sight vocabulary of 50 to 100 words is taught initially. Subsequent words are also learned as wholes, although not necessar-

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ily out of context. In contrast, phonics instruction emphasizes the relationship between *graphemes* (printed letters) and *phonemes* (their associated sounds). Unfortunately, in English the grapheme-phoneme correspondence is complex, and critics of this approach have argued that this lack of perfect correspondence causes confusion for the beginning reader. More recently, an approach to teaching reading that emphasizes meaning, called *whole-language* instruction, has been widely implemented in school districts, and the debate on how to best teach reading has focused on whole-language versus phonics approaches.

In this monograph, we first present some background material on different writing systems and the alphabetic principle. Then we discuss in more detail the starting point of learning to read (and the learning process) and the end point (taking into account insights from research in cognitive psychology, cognitive neuroscience, and connectionist models), while drawing implications for learning to read. We continue with a discussion of the methods that are used to teach children to read and what happens in classrooms where children are taught to read. We conclude by discussing research related to reading instruction.

WRITING SYSTEMS AND THE ALPHABETIC PRINCIPLE

Writing systems have developed around mixes of various principles that map a graphic form onto some unit of language. All modern writing systems connect to the spoken language, and do not directly encode nonlinguistic meanings. Written language, of course, does not directly use the sound waves produced by a human speaker: A book obviously is not a CD player. Instead, writing systems preserve abstract language units that are used in spoken language.

As illustrated in Figure 1, writing systems differ as to which language units are represented by graphic units. The elementary writing units can correspond to elementary speech sounds, such as phonemes (the /b/ sound in *bat*) and syllables, and to *morphemes*. Morphemes are the minimal units associated with meaning (such as the *cook* in *cooks* and *cooking*) and grammatical form (the *s* in *cooks* and the *ing* in *cooking*). These mapping options give rise to the three major kinds of writing systems—alphabetic, syllabary, and morpho-syllabic systems—that are found among the world's languages, often in intermixed form (DeFrancis, 1989; Gelb, 1952). Each system may have variations in orthography—the details of the mapping between graphic units and language units. And each system allows each of its basic units to map onto one or more phonological units (phonemes or syllables) or morphological units (morphemes).

English, Italian, Russian, and Korean are examples of *alphabetic* writing systems, in which graphic units (letters) are associated with phonemes. The letter *b* in the written word *bat* corresponds to the phoneme /b/ in the spoken word "bat." Arabic, Hebrew, and Persian are modified alphabetic systems, in which vowels can be omitted. In *syllabaries*, such as Japanese

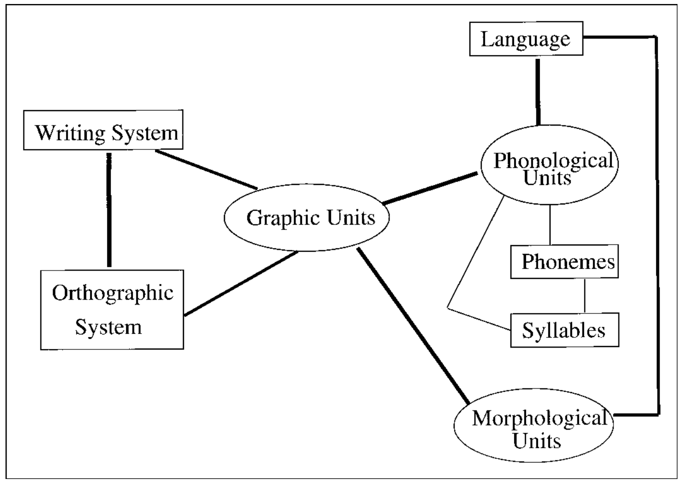

Fig. 1. The general relationships among writing systems, orthographies, and languages. A given language contains multiple units in both its basic phonological structure and its morphological structure. The phonological units include phonemes and syllables, but also intermediate units such as onsets (syllable beginnings) and rimes (vowels plus syllable endings). The morphological units are the units of meaning and grammatical form of a language, including the stems of words and word inflections. In a given writing system, one or more kinds of these phonological and morphological units are the units of mapping; the orthography is the system that controls the details of the mapping, including the extent to which the principles of mapping are intermixed. Adapted from Perfetti (1997).

Kana, the graphic units correspond to syllables. Systems whose units correspond to specific words or morphemes are usually called *logographic*. The logographic type of writing system is usually said to be represented by Chinese (along with the Japanese Kanji adaptation of the Chinese system). However, although its origins might be logographic, Chinese writing has evolved into a *morpho-syllabic* system (DeFrancis, 1989) in which the characters map onto syllable units that are also usually morphemes. The world is without an example of a writing system that encodes meaning in any pure form. In fact, the history of writing exhibits movement away from representation of meaning and toward more direct representation of sound (DeFrancis, 1989; Gelb, 1952; Hung & Tzeng, 1981).

The beginning reader must learn how a given writing system relates to spoken units in his or her language. Thus, critical details of learning to read depend on the writing system. Chinese, for example, can be read by associating each symbol with a meaning. Learning these form-meaning associations takes considerable effort. A vocabulary of 5,000 to 7,000 characters is typical of literate Chinese adults; during the first 6 years of school, children master about 3,500 characters by learning 500 to 600 per year. For the past half-century, Chinese children have been taught to read *pin yin* in the first grade prior to learning the character system. Pin yin is an alphabet, using letters of the Roman alphabet to spell Chinese words and adding marks to the spellings to indicate tones, the pitch variations that ac-company Chinese vowels. Thus, Chinese children can be said to learn alphabetic reading as a first step toward mastery of their own morpheme-based system (Perfetti & Zhang, 1995). Even with this head start, Chinese children spend more time at both school and home learning to read Chinese characters than American children spend in mastering an equivalent number of words. Part of this difference in time spent practicing reading undoubtedly reflects cultural factors (Stevenson & Lee, 1990). However, an additional factor is the difference in economy between an alphabetic system and a character system. An alphabetic system gains economy by mapping written units onto a small set of elements—the phonemes of a language—rather than the much larger set of morphemes a language has. This association of letters with phonemes is referred to as the *alphabetic principle*, and it allows alphabets to be *productive*; that is, a small set of symbols (letters) can be used to write an indefinitely large number of words. Productivity simplifies the learning problem, for example, allowing the child to use the mapping between four letters and their phonemes /t/, /p/, /s/, and /o/ to read *top*, *pot*, *stop*, *spot*, *pots*, and *tops*.

One of the main points of this monograph is that, despite the economy of the alphabetic principle, learning to read an alphabetic writing system like English is not easy. There are two main sources of difficulty: the abstract nature of phonemes (especially consonants) and the fact that most alphabets do not code each vowel with a unique symbol. Regarding the first issue, young children often have an imperfect idea of what phonemes are because they are abstractions rather than natural physical segments of speech. This is less of a problem for vowels than for consonants. For example, the vowel sound in *bat* is about the same as the one in *laugh*, and because vowels tend to have a relatively long duration, in both words the sound can be clearly heard and isolated. Thus, a teacher can point at the *a* in *bat* and say /æ/, and the child can hear the vowel sound clearly because it has sufficient duration no matter which sound precedes it. The pronunciation of a consonant, in contrast, can be highly dependent on the vowels that precede and follow it. For example, the /d/ in *dime* is different acoustically from the /d/ in *dome* or in *lid*. The letter *d*, then, corresponds to a phonemic representation that subsumes the /d/ sounds in these words but is not identical to any one of them. In such cases, it may be difficult for a child who is learning to read to discover and make mental representations of phonemes without some assistance. It also follows that applying the alphabetic principle will be difficult: A child who cannot identify an abstract phoneme (such as /d/) will have difficulty associating it with a specific grapheme (such as *d*).

The second obstacle to learning to read an alphabetic writing system is that many alphabets do not code each vowel with a unique symbol. For example, American English has more than a dozen vowel sounds but only five standard vowel letters (see Fig. 2). That means that *a*, *e*, *i*, *o*, and *u* have to do double and triple duty, even with some help from *y* and *w* (both of which can change vowel sounds, as in *saw* and *say*; *y* can also substitute for *i*). For example, *cat*, *car*, and *cake* each use the letter *a* for a dif-

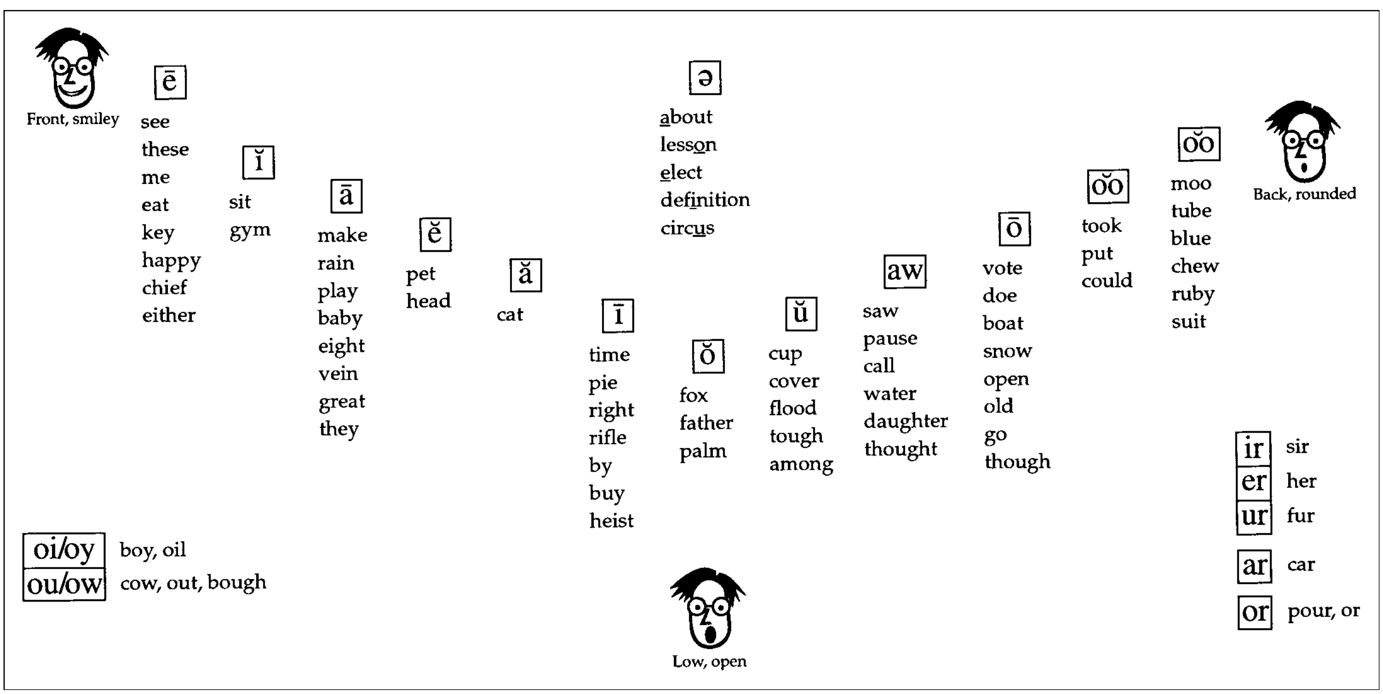

Fig. 2. A chart of the common spellings for vowels, positioned by place of articulation. The vowel sounds are represented by phonic symbols and are arranged according to mouth position, from front to back and high to low. Vowel spellings are more variant than consonant spellings and provide a challenge for beginning readers of English. From *Speech to Print: Language Essentials for Teachers* (p. 94), by L.C. Moats, 2000, Baltimore: Paul H. Brookes. Copyright 2000 by Paul H. Brookes Publishing Co. Reprinted with permission.

ferent vowel phoneme. Thus, the writing system exhibits economy (one letter represents these vowels rather than three) at the expense of complexity (the mapping between letter and sound is one-to-many). The trade-off is a good one because the resulting ambiguity is greatly reduced by other regularities in the writing system: For example, the pronunciation of *a* in *cake* is determined by the presence of the final *e*, and the pronunciation of *a* in *car* is determined by the presence of the *r* and the absence of the *e*, patterns that occur in many words. Thus, English is not as irregular as is often implied. However, it is more complex than many other alphabetic writing systems that adhere more closely to the principle that each letter should be associated with a single sound (Gelb, 1952; Hung & Tzeng, 1981).

The English writing system also exhibits a trade-off between phonological explicitness and morphological transparency. A fully explicit system would associate the letter *a* with a single vowel phoneme, such as the /æ/ in *fat*, and use a different symbol for the vowel in *fate*. The cost, however, is that this would obscure facts about morphological relationships between words. For example, the use of *a* to represent two different phonemes in *nature* and *natural* may be confusing as a guide to pronunciation, but it serves to remind the reader that the two words are morphologically related. This trade-off occurs repeatedly in English (N. Chomsky & Halle, 1968).

In summary, there are two main problems associated with understanding the alphabetic principle. First, phonemes are perceptual abstractions, and second, alphabets sacrifice phonological explicitness for symbol economy and morphological transparency, thereby complicating the orthography. Because of these problems, teaching methods that make the alphabetic principle explicit result in greater success among children trying to master the reading skill than methods that do not make it explicit. We discuss evidence for this assertion later.

THE DEVELOPMENT OF READING SKILL

How does a child come to acquire reading skill? What are the foundational competencies that reading builds upon? What is the course of development of these competencies? This section examines these questions. Before proceeding, we consider some definitional issues. Considerable confusion has been created by the fact that people mean different things when they refer to reading. Confounding the problem is a genuine and useful distinction between literacy and reading.

Literacy and Reading: Definitions

Each definition of reading can be defended on practical, logical, or programmatic grounds, and each has its own set of entailments that affect the framing of scientific and educational issues. According to broad definitions, reading is understood as a number of distinct literacy activities that have specific functions (e.g., reading bus schedules, newspaper ads, tax forms, or road signs; D.A. Wagner, 1986). Narrow definitions focus on the conversion of written forms into spoken language forms. The most common definition has been a midlevel one: Reading is getting meaning from print.

To see the value of the narrower definition, it is useful to make a distinction between literacy and reading. Literacy includes a variety of educational outcomes—dispositions toward learning, interests in reading and writing, and knowledge of subject-matter domains—that go beyond reading. These dimensions of literacy entail the achievement of a broad range of skills embedded in cultural and technological contexts. An extended functional definition is useful in helping to make clear the wide range of literacy tasks a society might present to its members. For example, literacy may be defined as including computer literacy, historical literacy, and scientific literacy, among others. Such a functional definition takes literacy as referring to a level of achievement, an extension of basic skill to reasoning and discourse in a domain (Perfetti & Marron, 1998).

However, the starting point for literacy is reading skill. Although many children are engaged in written language at an early age, schooling brings about specific expectations that all children will develop the ability to read and learn from texts. Our focus is on this necessary foundation. In this monograph, we use the term reading to refer to the process of gaining meaning from print. In focusing on reading's distinguishing features, we define learning to read as the acquisition of knowledge that results in the child being able to identify and understand printed words that he or she knows on the basis of spoken language. Because words already known to a reader are sometimes said to be represented in a mental lexicon or dictionary, this learning process can also be described as a modification of the mental lexicon such that it becomes *print addressable*. Put in other terms, learning to read is learning how to use the conventional forms of printed language to obtain meaning from words. This definition separates learning to read from other aspects of cognitive development. The distinguishing features of reading center on the conventionalized, graphic input to the reader and his or her conversion of that input into language-encoded messages. This view implies that the child learning how to read needs to learn how his or her writing system works.

How reading competence is achieved cannot be completely separated from how reading is taught. However, evidence for details of the course of reading acquisition in different instructional settings is sparse. That means that research that informs reading acquisition has to be considered at least partly independently of instruction. We examine research on reading acquisition after first considering what kinds of cognitive and language competencies are typically in place as a child enters school.

A Developmental Perspective on Reading

Learning to read builds on cognitive, linguistic, and social skills that have developed from the earliest age. The most important among these is the child's competence in language, which provides the basic foundation for reading.

Language development prior to school

Well before the start of school, children have acquired extensive knowledge of many aspects of language, including phonology, grammar, word meaning, and pragmatics (the social and communicative use of language). Although elements of each of these subsystems continue to be acquired over long periods (e.g., word meanings are acquired over the life span), children normally acquire the basics of each subsystem by age 4.

The phonological system is especially important for learning to read because, as we have observed, writing is a means of representing speech. What are the child's phonological abilities? An important part of the answer to this question is that whereas the basics of speech perception are acquired rapidly, mental representations of abstract phonological structure undergo further refinement well into the period when children begin to be exposed to writing. Newborns can discriminate all of the sounds (phonemes) that occur in spoken languages. Exposure to the sounds of one's native language, however, appears to reduce this ability; by 12 months, infants readily discriminate only the sounds of their native language (Werker & Lalonde, 1988). Note, however, that completely reliable discrimination between words that differ by only a single speech segment may not develop until the beginning of year 5 (Gerken, 1994). The reason for this slowdown after the rapid phonological development in the 1st year is unclear. One general possibility is that children develop holistic strategies in word perception, relying on prosodic and acoustic shapes more than segments (Gerken, 1994). If so, further development is postponed, being renewed when the child begins to sharpen phonological representations by taking account of segments (phonemes). One possible reason for this shift to segments is that the child's lexicon becomes larger, forcing finer discriminations (Jusczyk, 1985, 1992). Another possibility is that increased speech production by the child increases the demands for the child to represent speech in terms of ordered segments (Studdert-Kennedy, 1986).

As in the case of phonology, knowledge of grammar develops rapidly. The basic syntactic structures of the language are learned by age 2 (Bloom, Barss, Nicol, & Conway, 1994; Brown, 1973; Pinker, 1984). For example, children under 2 understand that "Big Bird is tickling Cookie Monster" means something different from "Cookie Monster is tickling Big Bird" (Hirsh-Pasek, Golinkoff, Fletcher, DeGaspe Beaubien, & Cauley, 1985, as cited in Bloom, 1994). This understanding is permitted by knowledge about how semantic notions (agent, recipient of action) map onto syntactic structures (first noun phrase, second noun phrase) in English. Grammatical knowledge gets refined during the preschool years, and the child comes to school equipped with fairly mature productive knowledge of his or her language.

Reading also depends on a developing knowledge of word meanings. Unlike grammar, which includes the productive machinery of language, word meanings are concepts that must be learned individually. Concepts and their lexical realizations are continuously added to what the child already knows and refined throughout development. The process starts early, with children typically producing their first words prior to their first birthday (Nelson, 1973). The comprehension of word meanings appears even earlier (Huttenlocher & Smiley, 1987). A dramatic increase in word knowledge (the *naming explosion*) occurs during the 2nd year, typically coinciding with the child's first use of multiple-word phrases (Bates, Bretherton, & Snyder, 1988). Although word meanings may not be part of the grammatical system itself, grammar and vocabulary appear to develop in tandem. Five- and 6-year-old children have vocabularies of 2,500 to 5,000 words (Beck & McKeown, 1991). Of course, vocabulary continues to grow after children enter school, and it is estimated that elementary-school children learn about 7 words per day (Nagy & Herman, 1987). However, individual differences in vocabulary related to reading ability and to demographics are readily seen (Beck & McKeown, 1991). For example, Graves and Slater (1987) reported that first graders from the upper socioeconomic status (SES) had about double the vocabulary size of first graders from the lower SES. (See also White, Graves, & Slater, 1990.)

Finally, children acquire some understanding of the social uses of language (pragmatics) throughout the preschool period (Ninio & Snow, 1996). They learn about basic conversational functions (e.g., turn taking) and conventional speech acts (e.g., requesting) that allow participation in a broad range of communicative situations (Snow, Pan, Imbens-Bailey, & Herman, 1996).

Beyond the basics of the phonological, grammatical, semantic, and pragmatic language subsystems (by which the child comes to produce and understand language) are other developments important for literacy and for the mature use of language forms. These developments are usually summarized by the phrase *metalinguistic awareness*—awareness of the aspects of language just discussed, as opposed to the ability to use them. Children make judgments, for example, about the correctness of sentence forms, using their knowledge of grammar (Pratt, Tunmer, & Bowey, 1984). Each of the linguistic subsystems—the morphological and phonological as well as the grammatical—is a potential area for metalinguistic awareness. Phonological awareness, which we discuss in more detail later, is especially important for learning to read alphabetic writing systems.

One type of metalinguistic awareness that is outside the productive components of language is also relevant for reading—the concept of a word. Although young children quickly recognize that things have names, the knowledge of single words as basic units of meaning develops gradually over the preschool period (Papandropoulou & Sinclair, 1974; Tunmer, Herriman, & Nesdale, 1988). Many preschool children appear to confuse the name with the object it refers to, referring to *snake* as a long word and *caterpillar* as a short one, for example. The relevance of this confusion for reading was demonstrated by Gleitman and Rozin (1977), who found that preschool children could not specify which of two printed words corresponded to each of two spoken words that differed in length (see also

Lundberg & Torneus, 1978). Thus, awareness of words as spoken forms is helpful but not sufficient for recognizing how such words are realized in print.

In summary, the child comes to school with a well-developed language system. Many elements undergo further development, but the functioning language system the child already has is sufficient to support reading.

Reading readiness and emergent literacy

Learning to read can be viewed from the context of other aspects of development, too: There are additional skills on which reading builds, and reading is a component of other developmental progressions. These alternative perspectives are reflected in two different approaches to preparing children to read. The skills tradition has been to teach and assess *reading readiness* skills in kindergarten (around age 5), as preparation for reading instruction in the first grade (around age 6). The prereading experience includes skills developed through exposure to visual forms and oral language, as well as experiences more directly related to reading (learning the alphabet).

A more recent alternative perspective takes a developmental view of literacy development. It emphasizes a developmental continuity between the cognitive tasks typical of the preschool period and learning to read (Sulzby, 1985). This view, known as *emergent literacy* (Clay, 1991), links the young child's activities around books to later opportunities for actual reading. Young children are characterized as developing concepts about the components of literacy, and their performance on various literacy-like tasks is used to place them on a developmental continuum. In this framework, the assumption is that reading and writing are developmental phenomena. Thus, literacy is characterized in developmental stages, with children's ideas about literacy being qualitatively different from those of literate adults (Ferreiro, 1986). The central idea of emergent literacy is that literacy emerges in various forms in development before being transformed into conventional reading and writing. This view has had considerable impact on teacher training and classroom practice. Classrooms organized on emergent-literacy principles emphasize a variety of communication opportunities—oral reading by the teacher, idea sharing by children, writing, and drawing—but with little emphasis on letter-sound relationships.

The developmental perspective is important for bringing into focus the accumulating knowledge that supports learning to read and providing a reminder that children come to school with varying amounts of knowledge about literacy activities. Some children will have acquired some knowledge of how written forms are mapped onto spoken language, but many will not have been so fortunate. At some point, children who learn to read must learn how their language is represented in the writing system. This knowledge is not a natural end point of a developmental progression; rather, it is usually the product of instruction and practice.

A learning perspective on learning to read

Learning to read is one specific example of learning. According to this perspective, the salient questions are (a) what is it that children learn when they learn to read? and (b) how does such learning come about? The answer to the first question is roughly that a child comes to learn that the writing system encodes his or her spoken language in a systematic way. The answer to the second question is that the child must be taught or else discover how this systematic encoding works.

Learning to Read an Alphabetic Writing System

For an alphabetic writing system, a child must learn that letters and letter strings correspond to speech segments. The alphabetic principle, the idea that written symbols are associated with speech sounds, is the key design principle of alphabetic writing and must be grasped by the child. Whether this knowledge is acquired implicitly (through the extraction of print-speech correspondences in text) or explicitly (through direct instruction) varies among children.

Alphabetic writing systems differ in terms of *orthographic depth* (Frost, Katz, & Bentin, 1987), or the consistency of the mapping between letters and sounds. In a *shallow* orthography, the mapping is highly consistent. Finnish, Italian, and Dutch are all shallower than English because letters are more reliably associated with particular phonemes. English is deeper because the spelling-sound correspondences are more variable, as illustrated earlier. In comparing different orthographies' complexity and ease of learning, one needs to consider not just depth, but also many other features of orthographies and the languages they represent, as well as trade-offs between orthographies and languages (Seidenberg, 1992). For example, English has many irregularities at the level of individual graphemes and phonemes, but most of them occur in short, high-frequency words, such as *have*, *was*, and *the*. Moreover, English is less inconsistent at the level of the larger, subsyllabic unit called the *rime* (a vowel plus syllable ending; Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995), and this unit is highly salient in early reading (Goswami, 1993).

Good readers have a good grasp of spelling-sound correspondences, as evidenced by their ability to sound out novel words (Blachman, 1989). The extent to which learning the alphabetic principle depends on explicit instruction is not clear. Some evidence suggests that it may be difficult for children to infer the principles of correspondence without instruction (Byrne, 1991), whereas other research suggests that this is exactly what successful readers do in the absence of direct instruction (Thompson, Cottrell, & Fletcher-Flinn, 1996). Both conclusions seem reasonable. Without direct instruction, learning to read successfully is not guaranteed, but some children do learn to read without such instruction. To the extent that learning occurs, whether by direct instruction or implicit learning, the problems posed by an inconsistent orthography are overcome just as other inconsistent-mapping problems in human learning are overcome—by practice. With sufficient effective practice, children acquire a context-sensitive mapping of relations between graphemes and phonemes (and larger units). So *-ow* comes to be pronounced one way in the context *n*_ _ and another way in the context *l*_ _. As we discuss next, initial success in learning to read depends on the extent to which the child has developed knowledge of individual speech sounds.

Phonological Awareness

The central problem in learning to read English is that although discovering and applying the alphabetic principle is a key to success, this is not an easy achievement for beginning readers. Concerning this discovery, Ehri (1979) wrote, "If the light were not so gradual in dawning, the relationship between speech and print might count as one of the most remarkable discoveries of childhood" (p. 63). As already noted, this is a difficult learning problem because (a) phonemes are abstract categories, (b) they have not been fully developed through the use of speech by the time reading instruction begins, and (c) there are inconsistencies in the mapping between spelling and these units in deep alphabetic orthographies such as the one for English.

The term *phonological awareness* (or *phonemic awareness*) refers to children's knowledge of the internal sound structure of spoken words. There is a large literature examining how children's level of phonological awareness relates to their success learning to read. Phonological awareness is assessed by tasks such as deciding if two words rhyme or if they start or end with the same sound. Not surprisingly, children who perform well on such tasks do markedly better in early reading than those who do not. And, conversely, children who score poorly on phonological-awareness tests prior to entering school are much more at risk for not learning to read effectively than children who score well (Bradley & Bryant, 1978, 1983).

The strong relationship between phonological awareness and learning to read has been shown by numerous studies in several languages (Ball & Blachman, 1988; Blachman, 1989; Fox & Routh, 1976; Lundberg, Olofsson, & Wall, 1980; Stanovich, Cunningham, & Cramer, 1984; Tunmer et al., 1988; R.K. Wagner & Torgesen, 1987). Other studies have suggested that instruction can bring gains in phonological awareness and, in turn, in reading (Ball & Blachman, 1988; Bradley & Bryant, 1983; Byrne & Fielding-Barnsley, 1991; Lundberg, Frost, & Petersen, 1988; Mann, 1991; Perfetti, Beck, Bell, & Hughes, 1987; Treiman & Baron, 1983; Vellutino & Scanlon, 1991). Moreover, reading programs that emphasize phonological-awareness training have proved to be successful in classrooms (Blachman, 1989; Wise, Ring, & Olson, 1999). Effective reading instruction can help teach children what they need to know about both the alphabetic principle and phonological awareness. Furthermore, phonological training can remediate problems for children who have not learned to read (Blachman, 1989; R.K. Olson, Wise, Ring, & Johnson, 1997).

The relationship between knowledge of phonological structure and ability to read is reciprocal. At the start of reading instruction, children's knowledge of phonological structure is partial: Although they have begun to discover aspects of the internal structure of spoken words, they typically have not converged on explicit representations of phonemic segments. These partially structured phonological representations are sufficient to support the use of spoken language. Exposure to orthography and explicit instruction in the mappings between spelling and sound lead to further refinement of children's phonological representations, in the direction of more explicit representations of segments and other units such as onsets and rimes. Learning to spell also contributes to this process (Shankweiler & Lundquist, 1992). These refinements in turn facilitate further development of reading skill.

These observations suggest that the child's development of phonemic representations is more closely tied to reading than to speech. No child ready to read has trouble hearing that *bad* and *pad* are different forms with different meanings. Making such distinctions does not require the use of phonemes; they can be based on acoustic phonetic information (such as the difference in voice onset time, the lag between the release of the consonant and the onset of the vowel, that differentiates /b/ from /p/) to which even infants are sensitive, or on the basis of whole syllabic representations. In fact relatively few preschool children demonstrate an awareness of phonemes despite showing awareness of syllables (I.Y. Liberman, Shankweiler, Fischer, & Carter, 1974). The alphabetic writing system both builds upon and facilitates the development of phonemic representations. It is in keeping with the alphabetic principle that a single letter *d*, for example, is used to represent the category of sounds called the phoneme /d/. Thus, the alphabetic principle was a unique discovery in the evolution of writing systems (Gelb, 1952), and it is a discovery not made by all children on their own.

Three types of evidence indicate that reading experience plays a role in developing phonemic knowledge: (a) studies of illiterate adults (Morais, Cary, Alegria, & Bertelson, 1979), (b) longitudinal studies of first graders (Perfetti et al., 1987), and (c) studies of Chinese readers (Mann, 1986; Read, Zhang, Nie, & Ding, 1986). For example, Morais et al. compared how illiterate and recently literate Portuguese speakers from the same community performed on phonological-awareness tasks. The illiterate participants could not add or delete an initial consonant from a spoken utterance, but the adults who had recently become literate by attending adult education classes performed the task successfully. The implication is that experience with an alphabetic orthography may be necessary for an individual to develop full phonological representations.

Experience with an alphabetic orthography also reduces the impact of dialect variations on phonological awareness. Despite regional dialects, speakers of American English share knowledge of phonology, morphology, and semantics. For example, some Americans no longer explicitly represent final consonant clusters in speech (e.g., *test* is pronounced "tes"). However, there is an underlying tacit awareness of these phonemes in all speakers, whether they are literate or not. This awareness is evidenced by their overt phonological representation in inflected forms of a word. That is, /st/ is pronounced in "testing" by a speaker who would drop these phonemes in "test." However, this tacit knowledge is not sufficient for illiterate speakers to identify the final sound in "test" as /t/ (Morais et al., 1979). Furthermore, for literate speakers, there is the awareness that despite reduction of consonant clusters in speech, the phonemes /st/ are explicitly represented orthographically in spelling (*test*). Thus, experience with an alphabetic orthography draws conscious attention to the underlying phonological representation of words and prompts literate speakers to write final consonant clusters even though they do not pronounce them in speech.

Finally, we add a note about the relationship between intelligence and phonological awareness. It is tempting for laypersons and parents to assume that intelligence plays a critical role in learning to read. In the extreme, of course, this must be true. However, three lines of evidence indicate that in general it is not. First, studies of children who learn to read early (prior to entering school) indicate that there is not a strong relationship between IQ and early reading (Briggs & Elkind, 1973; Durkin, 1966); although the mean IQ of early readers is above average, the range of their IQ scores indicates that many children who are early readers do not have unusually high IQs. Second, a number of studies have found that IQ is only weakly and nonspecifically related to reading achievement in the first and second grades (Stanovich, Cunningham, & Feeman, 1984). Finally, children who have difficulty learning to read often have above-average IQs (Rawson, 1995). Hence, it is not surprising that phonological awareness is the strongest predictor of early reading skill (M.J. Adams, 1990).

Learning to Read at the Beginning

Prior to the onset of direct instruction in grapheme-phoneme correspondences, when children's knowledge of phonological structure is limited, their earliest attempts at reading are revealing. Gough (1993; Gough & Juel, 1991) demonstrated that 5-year-old children, as a first pass at reading, associate features of print with spoken word names, apparently without using the orthography of the words. In one experiment, children learned to recognize a word by use of a thumbprint placed on a card containing the printed word. When the thumbprint was absent, so was recognition. In another experiment, children were found to associate selective parts of the printed word to the spoken word. After being shown a short list of words, they were presented with either the first letters or the end letters of the words. Children who could identify the word based on its first letters failed to identify it when presented with only the final letters; children who could identify the word based on the final letters failed to identify it when presented with its initial letters. This suggests that attending to all the letters of a word is not something that all children do at the beginning (see also Rayner, 1988). Gough's study does not imply that 5-year-olds cannot use letter forms and their associated speech forms. It merely shows that in the absence of reading instruction and knowledge of letter-sound correspondences, children can approach a reading task by memorizing the visual images of words, without learning how the sound-letter system works. Moving to productive reading requires more than memorizing printed words.

Theories of Learning to Read

Progress in learning to read has often been viewed as a series of stages (Chall, 1983; Ehri, 1991; Frith, 1985; Gough & Hillinger, 1980; Marsh, Friedman, Welch, & Desberg, 1981). The earliest stage can be characterized as attempts to learn associations between visual features of graphic forms (not complete orthographic word forms) and spoken words. A subsequent stage of graphic-phonological decoding, in which children learn the letter-sound associations, brings on a truly productive capability enabling them to read words they have not seen before. The use of letter names as a bridge to phonology is a beginning step (Ehri, 1991). Alternative theoretical accounts emphasize the incremental acquisition of individual word representations rather than discrete stages (Perfetti, 1992). In each of these theories, phonology plays an important role in helping the child establish word-specific orthographic representations, a proposal that has come to be known as the *bootstrapping hypothesis*, the idea that attempting to decode an unfamiliar word is a form of self-teaching that allows the child to acquire an orthographic representation for the word (Share, 1995).

Stage theories of reading development

A proposal by Gough (Gough & Hillinger, 1980; Gough & Juel, 1991; Gough & Walsh, 1991) illustrates stage theories. The first stage is a visual association stage, which is followed by a second stage of decoding-based learning. In the first stage, the child, absent any knowledge of decoding, uses any conceivable source of information to discriminate one word from another. In doing this, the child builds up a set of words that can be recognized on the basis of partial visual cues (e.g., an initial letter). Gough called this first stage *selective association* because the basic learning mechanism establishes idiosyncratic associations between some part of a printed word and the name of the word. Under the right circumstances, including an increase in phonological awareness and an intention to encode all of the letters of the word, the child moves into the *cipher* stage of true reading (Frith, 1985, called this the *alphabetic* stage). As the child reaches the limits of learning associations, there is pressure to adopt a new procedure, one based on the alphabetic principle. Early in reading, for example, a child can attend to the *m* in *mouse* to distinguish *mouse* from *cat* and *house*. But as *moon* and *moose* are encountered, the association cue that was sufficient earlier becomes insufficient. This problem then fuels progress in the child's attending to more orthographic information.

An alternative view comes from Ehri (1980, 1991; Ehri & Wilce, 1985). In her theory, there is no purely visual stage (as in Gough's account). Rather, children use letter names as cues to word identification from their very first opportunity, as when the letter *j* provides its name ("jay") as a cue for reading the word *jail*. Learning the alphabet, not necessarily the alphabetic principle, is the key that moves a child into the first stage of reading, called *phonetic cue reading*. In this stage, the child reads by using some of the associations between the printed letter forms and the phonetic cues of some of the letters (their phonological associations). As in the selective association stage identified by Gough, the child is reading primarily by using incomplete, selective associations. But in Ehri's account, the associations are systematic and based on letter-sound correspondences. The process of learning to read involves establishing complete word representations that have both phonological and orthographic components.

A nonstage incremental theory

The theories we have discussed so far assume that children learn to read by progressing through a series of stages defined by different types of decoding strategies. Other theories emphasize the incremental nature of development (Munakata, McClelland, Johnson, & Siegler, 1997). The basic idea is that many types of knowledge are acquired gradually on the basis of many experiences. What appear to be qualitative shifts in strategy result from changes in the amount and complexity of the information that has been acquired. Consider, for example, the observation that children progress from an early logographic stage (in which printed words are directly associated with meanings and pronunciations) to an alphabetic stage (in which they make use of knowledge concerning components of words such as letters and phonemes). Research (see Using Connectionist Models) has shown that this shift does not require a change in strategy or in the hypothesis about the nature of print. Rather, it can be accounted for by a process of gradual learning based on many examples. In other words, progress to an alphabetic stage can be viewed as a change in behavior: increased sensitivity to the internal structure of words and the correspondences between subword components and pronunciations (as the alphabetic principle is discovered). Thus, whereas stage theories provide qualitative characterizations of changes in children's performance, the connectionist theory attempts to explain how these changes arise from more basic mechanisms.

In Perfetti's (1992) nonstage framework, learning to read involves the acquisition of increasing numbers of word representations that can be accessed by their spellings (quantity acquisition) and changes in the *specificity* and *redundancy* (quality dimensions) of individual words' representations. As a child learns to read, his or her representations of words increasingly have specific letters in their correct positions (i.e., increased specificity). Also, these representations become phonologically redundant. The addition of specific grapheme-phoneme correspondences for a word is redundant with the word-level pronunciation of the word. Such redundancy assists word reading by allowing both letter-level and word-level processes to produce a word's pronunciation. Together, increasing specificity and redundancy allow high-quality word representations that can be reliably activated by orthographic input. As individual words become fully specified and redundant, they move from what is called the *functional* lexicon, which consists of words that can be read only with effort, to the *autonomous* lexicon, which includes words that can be read with minimal effort. This theory has been applied to explain individual differences in reading skill (Perfetti & Hart, in press).

All the theories we have discussed are compatible in many respects and indeed share the fundamental assumption that achieving reading skill requires use of the alphabetic principle. This principle, effectively applied to print-sound connections and supported by phonological sensitivity, is the critical factor in early success in learning to read (Bradley & Bryant, 1983; Ehri & Sweet, 1991; Juel, Griffith, & Gough, 1986; Share, 1995; Tunmer et al., 1988).

Mechanisms of Progress in Learning to Read

Beyond these rudimentary beginnings, progress in learning to read is fueled by several factors that center on increasingly adaptive use of the alphabetic principle and the establishment of orthographic patterns that are associated with pronunciations. Successful learners apply their primitive understanding of the alphabetic principle to their encounters with words, which are turned into opportunities to apply and extend their alphabetic knowledge. Studies by Stuart (1990; Stuart & Coltheart, 1988) illustrate this point: The extent to which children made phonological errors (i.e., misidentified a word as a similar-sounding word) in word reading early in the first grade predicted their end-of-year reading achievement. Nonphonological errors, including errors that shared letters but put phonemes in the wrong position (e.g., *like* for *milk*), were associated with low end-of-year achievement. The point at which phonological errors became more common than nonphonological errors coincided with when the child attained *functional phonological skill* (i.e., knew at least half the alphabet and was successful in at least some tests of phonological sensitivity). Also, the level of a child's phonological sensitivity (awareness) corresponded in some detail to the level of the child's achievement in word reading.

Truly productive reading, the ability to read novel words, comes only from an increase in knowledge of how orthography relates to phonology. This requires attention to letter strings and the context-sensitive association of phoneme sequences to these letter strings. This is where sensitivity to phonological structure should play its most important role. Children who have attained this productive level of reading can read pronounceable nonwords, and their errors in word reading show a high degree of phonological plausibility. These considerations, along with demonstrations that success in learning is associated with a phonological approach to reading (Stuart & Coltheart, 1988), suggest that the main learning mechanism available to the child is *phonological recoding*, recoding of spellings into pronunciations. A model of how this mechanism works comes from Share (1995), who emphasized the role of self-teaching in learning to read words. An important focus in this model is children's attempts to phonologically recode words. One opportunity to do this arises during reading aloud either to a parent or to a teacher. The feedback from these attempts gradually builds up the orthographic representation of specific words. The role of phonology, in effect, is to influence the development of word-specific orthography. The letter-by-letter processing in sequential decoding of words may be the main factor in producing high-quality word representations that incorporate the letter constituents of those words (M.J. Adams, 1990; Ehri, 1980; Perfetti, 1992; Venezky & Massaro, 1979). Several studies have found that a few exposures to a word may be sufficient for the child to acquire word-specific orthographic information (Brooks, 1977; Manis, 1985; Reitsma, 1983), increasing the specificity and redundancy of the child's printed-word lexicon. Although other mechanisms might promote the acquisition of print-accessible word representations, phonological recoding is the most effective mechanism (Share & Stanovich, 1995).

The importance of a phonological-recoding mechanism, therefore, goes beyond its role in learning decoding rules. In addition, the application, even the imperfect application, of this mechanism helps the child learn specific word forms. Models such as Share's (1995) self-teaching model emphasize the child's acquisition of individual word representations, rather than stages of development. Such models (Harm & Seidenberg, 1999; Perfetti, 1992; Share, 1995) ask "which words can a child read?" rather than "what stage is the child in?" The rapid buildup of the child's lexicon through reading promotes many words to a functionally high-frequency status (i.e., they become familiar). Texts that contain a high proportion of familiar words will be read well, and the occasional low-frequency word provides an opportunity for phonological self-teaching. Because the child will face many low-frequency words over time, the phonological-recoding mechanism is a very powerful, indeed essential, mechanism throughout reading development, not merely for beginners. Research has shown, for example, that third-grade children who are skilled in reading can quickly and accurately read a novel word that they have previously only heard; less skilled readers tend to reach the same level of accuracy and fluency reading these words only when they have previously actually seen the words (Hogaboam & Perfetti, 1978).

An important fact about the acquisition of reading skill is that it improves with practice. What is it that is improved? Practice improves many components, but central among them is knowledge of individual words. Experience in reading allows the increasingly accurate representation of a word's spelling (its specificity), as well as a strengthening of the connection between the phonological form and the spelling, and this specificity increases the speed of word identification. Practice in reading brings about an increasing facility with words because it increases the quality of lexical representations. It turns low-frequency words into high-frequency words. The result is what is commonly known as *fluency* in reading. Fluency entails developing rapid and perhaps automatic word-identification processes (Laberge & Samuels, 1974). The main mechanism for gains in automaticity is, in some form or another, practice at consistent input-output mappings (Schneider & Shiffrin, 1977). In reading, automaticity entails practice at retrieving word forms and meanings (the output) from printed words (the input). Automaticity is a characteristic of specific words, not readers. Words move from the functional lexicon to the autonomous lexicon as a result of practice reading text.

Experience not only builds automaticity, it also establishes an important lexical-orthographic source of knowledge for reading (Stanovich & West, 1989). This lexical-orthographic knowledge centers on increasing familiarity with the letters that form the printed word. It is reflected in performance on tasks that assess spelling knowledge, as opposed to those that assess mainly phonological knowledge, and is indexed by the amount of reading a person has done. Phonological and lexical-orthographic abilities are correlated, but each makes a unique contribution to reading achievement. The result is two complementary but overlapping kinds of knowledge that support the reading of words.

One benefit of reading practice is that it supports comprehension ability, vocabulary growth, and spelling skill. Stanovich (Stanovich & Cunningham, 1992; Stanovich & West, 1989) measured college students' reading experience (or *print exposure*) and correlated it with measures of cognitive and reading abilities. On the Author Recognition Test, a print-exposure measure, readers are given a list of 80 names, 40 names of real authors and 40 other names, and are asked to indicate which are the names of authors. Correctly identifying the real authors on this test is presumably an indicator of reading experience, and greater reading experience, measured in this way, correlated with better comprehension, spelling, and vocabulary skills. Furthermore, print exposure accounts for variance in word recognition and spelling that is not accounted for by phonological processing in adults (A.E. Cunningham, Stanovich, & Wilson, 1990; Stanovich & West, 1989) and children (A.E. Cunningham & Stanovich, 1991).

Notice that the Author Recognition Test allowed differentiation of print exposure within a relatively homogeneous population of college-age readers. Print exposure appears to be the literacy equivalent of practice in skills like chess; just as practice in chess separates grand masters from excellent tournament players, practice at reading separates skilled readers from less skilled readers in the college population. Thus, this research is important in establishing that the amount of reading makes an independent contribution to reading skill. This contribution appears to be mediated not by phonological processes, which readers must acquire anyway, but rather by the more general facilitation that arises from accessing words repeatedly. It is the dilemma of the less able reader that he or she will not get as much practice as the more able reader. The gap between more and less able readers thus increases with time (Stanovich, 1986). Furthermore, A.E. Cunningham and Stanovich (1997) found that 1st-grade reading ability was a strong predictor of 11th-grade reading ability and suggested that the rapid acquisition of reading ability helps develop the lifetime habit of reading. Thus, although it might be tempting to believe that initial differences in reading ability wash out over time, the data suggest just the opposite.

Spelling

Children's initial expression of the alphabetic principle appears more often in spelling than in reading (Frith, 1985). Indeed, children's attempts at spelling prior to formal reading instruction typically reveal an understanding of basic letter-sound associations (C. Chomsky, 1970; Read, 1971). In producing spellings, preliterate children often use the sounds associated with the names of the letters, spelling *car* as "KR," for example. In effect, this spelling uses the name of the letter *R* (/ar/) to capture both vowel and consonant. As Treiman and Cassar (1997) pointed out, the tendency to use letter names in spelling is affected by phonological properties of the letter names. *R* is more likely to be used for /ar/ than *T* is for /ti/ or *L* for /ɛl/ because it is harder to segment the /r/ from its preceding vowel than to segment the /t/ and /l/ from the vowels following and preceding them. These observations have two important implications: Treiman and Cassar's findings about *R*, *L*, and *T* reflect the difficulty of reliably segmenting syllables into phonemes and reinforce the conclusion that full awareness of phonemes is difficult to achieve prior to literacy. But the broader implication is that one underestimates the child's potential grasp of the alphabetic principle—or at least the idea that speech sounds are associated with letters—if one considers only decoding. Spelling is the primary early indicator of this potential and can form the basis for later expression of the alphabetic principle in decoding.

It is also clear, however, that early spellings are guided by more than the child's attempts to map sounds onto letters. Treiman (1993; Treiman & Cassar, 1997) has shown that at an early age children become sensitive to both the orthographic structures and the morphological structures that are present in spellings. Even in first grade, children's classroom spellings reflect a number of orthographic conventions, including, for example, the fact that *ck* never occurs as a spelling of /k/ at the beginning of a word, but does occur following a vowel. First graders show their sensitivity to morphology when they refuse to spell *dirty* as "dirdy," even though the /d/ sound is what is heard. The conventional spelling honors the fact that *dirty* contains the lexical morpheme *dirt* plus a suffix. Children are more likely to substitute a *d* for a *t* in a single-morpheme word such as *duty* (Treiman, Cassar, & Zukowski, 1994). At this age, children's use of morphology is very incomplete, and many of their errors reflect a preference for spelling a sound over spelling a morpheme. But clearly, at least as soon as literacy is under way, children begin to show an awareness that conventional spellings honor both phonological and morphological structure, as well as conventional orthographic constraints.

Eventually, in many languages, the learner confronts an important fact about spelling: Typically, the mapping from pronunciation to spelling is less consistent than the mapping from spelling to pronunciation. Reading is more reliable than spelling. An important idea about the relation between spelling and reading comes from recent research on word identification. The more ways a sequence of phonemes can be spelled, the longer it takes to read a word containing that sequence. For example, *shelf* is more efficiently read than *sneer* because its rime unit /ɛlf/ is always spelled *elf*, whereas the rime unit /ir/ is spelled variously as *eer*, *ear*, *ier*, or *ere*. Notice that this is not a question of consistency in the direction of orthography to phonology: *eer* is always pronounced /ir/. Stone, Vanhoy, and Van Orden (1997) reported the first demonstration of this backward consistency effect (i.e., effect of phonology on orthography). Although the reliability of this phenomenon is a focus of research (Peereman, Content, & Bonin, 1998), it is interesting to note the obvious implication it would have for reading and spelling. If reading words really includes a feedback mechanism from phonology to orthography, then the reader would not merely convert a written input into a phonological representation but would also, in effect, verify (rapidly and unconsciously, to be sure) that the phonological representation could be spelled in the way presented. More generally, the hypothesized feedback mechanism illustrates one way that spelling and reading may be intimately related.

The relationship between reading and spelling is represented in Figure 3, which presents a system in which lexical representations include information needed for both spelling and reading (both letter and phoneme strings). Some identities (letters or phonemes) can be missing or variable or incorrectly specified, especially for children. Reading can be successful with an underspecified representation, but spelling cannot.

It has been observed that children can sometimes spell words that they cannot read (Bryant & Bradley, 1980). However, this phenomenon is no more frequent than that of failing to read a word after having read it successfully once before, or failing to spell a word after successfully spelling it once before (Gough, Juel, & Griffith, 1992). Thus, variability in performance, which is presumably due to an unreliably specified mental representation, characterizes both reading and spelling and is consistent with the assumption that reading and spelling have a common representation system.

It is the case, of course, that spelling is more difficult than reading, and indeed many skilled readers identify themselves

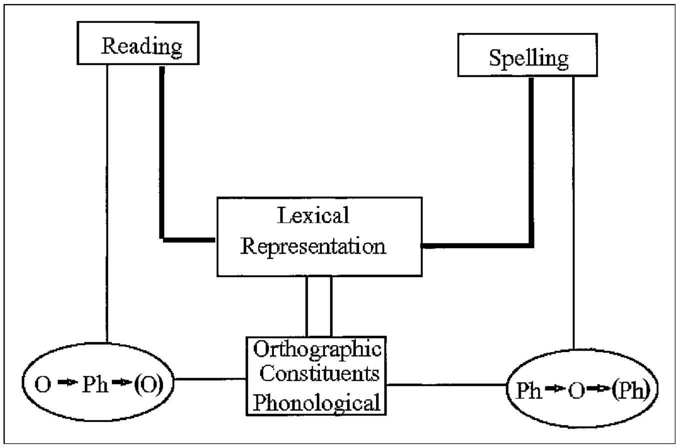

Fig. 3. The spelling-reading relationship. Both processes use a lexical representation that contains orthographic (O) and phonological (Ph) constituents (i.e., graphemes and phonemes). These constituents can be incompletely specified in the representation. A conventional spelling process requires complete specification of constituents, whereas the reading process, which needs only to discriminate a presented word from other words, does not. The two ovals represent the directions of the reading and spelling processes. Reading transforms orthographic representations into phonological ones (with a possible feedback to orthography), and spelling transforms phonological representations into orthographic ones (with a possible feedback to phonology), as explained in the text. For simplicity, the figure ignores the important role played by morphology in both reading and spelling. Adapted from Perfetti (1997).

as "terrible spellers." Spelling is typically more difficult than reading not because they use different representations, but because spelling requires additional processes that benefit from specific practice at spelling. Because spelling requires production, whereas reading requires recognition, success in reading does not lead automatically to success in spelling. Interestingly, this is true even among children who are learning to read a shallow orthography through phonics-based teaching, as is the case in the Netherlands (Bosman & Van Orden, 1997). Children's spelling ability benefits from instruction that specifically targets the production of conventional spellings.

Comprehension

It can be reasonably argued that learning to read enables a person to comprehend written language to the same level that he or she comprehends spoken language. Thus, reading comprehension is not so much an issue of reading as it is an issue of general language comprehension. However, the reality is that assessments of reading skill are concerned with reading comprehension and that this concern reflects the expectation that children should understand what they read. Thus, although we focus more in this monograph on word reading than on comprehension, it is important to emphasize the importance of comprehension as a part of a more complete picture of reading skill.

There are several important points to emphasize in considering comprehension. First, as we just pointed out, comprehension is a matter of language understanding, not a unique feature of reading. Thus, the acquisition of reading comprehension skill includes two highly general components: the application of nonlinguistic (conceptual) knowledge and the application of general language comprehension skills to written texts. An important question for instruction is the extent to which either of these applications needs to be targeted in the classroom. The research literature is clear in showing profound effects of specific conceptual knowledge on the comprehension of texts (Alba & Hasher, 1983). Knowledge is a matter of general education, inside and outside the classroom, and has little specific claim on reading, however. Its contribution, as important as it is to every comprehension event, is not an intrinsic component of reading, which includes mechanisms that can compensate to some extent for limited knowledge (Perfetti, 1985).

Two conclusions about the role of comprehension in learning to read seem warranted. First, comprehension is critical as part of the acquisition of reading skill. Second, much of what is important about comprehension is highly general to language, and not unique to reading. Evidence for this comes from the high correlations (in the range of $r = .9$) observed between written and spoken language comprehension among adults (Bell & Perfetti, 1994; Gernsbacher, 1990; Gernsbacher, Varner, & Faust, 1990). These correlations are lower for children and increase with age (Curtis, 1980; Sticht & James, 1984), as would be expected if general language-comprehension skills show their importance as basic literacy skills are mastered.

If written and spoken language comprehension go together, what about children who can read words but whose reading comprehension is not as good as their spoken language comprehension? The frequency of such cases may be exaggerated by the anecdotal impressions of teachers who have not had the luxury of assessing carefully both the comprehension (spoken *and* written) and word-identification skills of such children (Perfetti, 1985). There is surprisingly little convincing documentation of pure reading comprehension deficits accompanied by high levels of both word-identification and listening comprehension skill. Some research (Stothard & Hulme, 1996; Yuill & Oakhill, 1991) suggests that some children have better decoding than reading comprehension skills. However, these children appear not to have specific reading problems, but rather to have general comprehension problems associated with both spoken and written language (Stothard & Hulme, 1996).

It is important to note that spoken language skills, acquired in conversation and play, may not transfer to reading comprehension for typical written texts. Indeed, there are differences between spoken and written language that should lead to processing differences (D.R. Olson, 1977). This would mean that skills developed in oral settings would not transfer to spoken versions of written texts either. The high correlations between spoken and written language comprehension have been obtained in studies that use a single set of materials that are presented in two different modalities. These studies have not correlated spoken comprehension of typical spoken language with written comprehension of typical written language. Accordingly, the high correlations partly reflect the effects of specific text material that is more typical of written than spoken language. The conclusions that reading comprehension depends on spoken comprehension may need to be qualified a bit. It may be more correct to say that the potential for comprehending a written text is set by the ability to comprehend that same text when it is spoken. The typical differences between the uses of spoken and written language suggest that special efforts directed toward the distinctive aspects of written text comprehension may be warranted as part of reading instruction, especially as written texts become more complex later in elementary school.

Implications for Teaching Reading

The instructional goals for alphabetic systems seem clear: Children need to learn that the letters of their alphabet map onto speech segments of their language. However, controversies over how to teach reading abound. Rather than focusing on letter-sound correspondences, the dominant instructional approaches for the past 20 years were meaning focused, built around story reading, exposure to print, and enhanced language environments. Nevertheless, for more than 30 years, research has supported the effectiveness of methods that are based on direct instruction in phonics or decoding. In a major review of research on reading acquisition titled *Learning to Read: The Great Debate*, Chall (1967) concluded that the majority of the research tended to favor phonics instruction, and her comprehensive study has been confirmed by more recent studies (M.J. Adams, 1990; Foorman, Francis, Fletcher, Schatschneider, & Mehta, 1998). However, the practice of reading instruction has remained out of touch with research, emphasizing a variety of language activities but minimizing the teaching of grapheme-phoneme relationships. Much of the debate has been fueled by philosophical stances and professional advocacies that have little to do with the research basis for effective teaching (Stanovich, 2000). However, there are recent indications that a stronger consensus is emerging in favor of research-guided practice.

Summary

Most children come to reading instruction with normally developed language abilities, which can provide the foundation for learning to read. Those children with less developed language abilities still benefit from phonological-awareness instruction. The central achievement of early reading is learning to read words, which requires knowledge of the phonological structures of language and how the written units connect with the spoken units. Phonological sensitivity at the subword level is important in this achievement but is not provided to all children by the spoken language in their environment. Phonological training helps the acquisition of reading. Very early, children who will turn out to be successful in learning to read use phonological connections to letters, establishing decoding as a mechanism for productive reading, the ability to read previously unencountered words. An important mechanism for this is phonological recoding, which helps the child acquire high-quality word representations. Gains in fluency (automaticity) come with increased experience, as does increased lexical knowledge, which supports word identification.

DEVELOPMENTAL DYSLEXIA

Individual differences in reading achievement are often due to differences in the ability to read words, and, indeed, children and adults display a wide range of ability to read words. When reading skill is sufficiently low relative to certain standards, the individual has a disability called *dyslexia*. In discussing dyslexia, we need to distinguish between *acquired dyslexia* and *developmental dyslexia*. Individuals who have acquired dyslexia were previously able to read quite fluently, but because of some type of brain injury (resulting from head injury, stroke, or degenerative neuropathology, such as Alzheimer's disease), they can no longer read efficiently. There are several patterns of acquired dyslexia (see Coslett, 2000), and we make reference to some of them here to support certain arguments.

Our focus, however, is on developmental dyslexia, which varies along a continuum from mild to severe. The term has traditionally been reserved to apply specifically to children who have normal intelligence and do not exhibit frank sensory or neurological impairments (Critchley, 1970). More generally, the dyslexia label is typically restricted to individuals whose reading levels are discrepant from the potential implied by their IQs. However, children who have reading disability appear to present the same reading problems whether or not they meet the discrepancy criterion (Stanovich & Siegel, 1994). In either case, these children have not mastered the task of learning to read efficiently, and intervention by the end of the second grade is often critical for their successful reading development (Rawson, 1995). Their reading difficulties must be understood in terms of underlying cognitive processes that can go wrong. A signature problem for all struggling readers is their poor skill at reading words and pseudowords (nonwords, like *mard*, that are pronounceable and could be words because they conform to English spelling rules). These problems, as we discuss later in this section, are often traceable to problems in phonological processing.

Contemporary research suggests that developmental dyslexia is caused largely by language-related deficits, whose neurological bases are beginning to be identified (Pugh et al., 2000). Although these deficits sometimes affect other aspects of behavior, they have a particularly large impact on reading. We now describe some of the suspected causes of developmental dyslexia.

The Phonological-Deficit Hypothesis

Given the extensive evidence indicating the importance of phonological information in reading acquisition, it is not surprising that the leading hypothesis about the cause of developmental dyslexia is that it is due to deficits in the representation and use of this information (Snowling, 2000; Stanovich & Siegel, 1994). Phonological information plays important roles in reading familiar words and sounding out new ones; phonologically based working memory capacities are used in integrating and comprehending words in sentences (Gathercole & Baddeley, 1989; Jorm & Share, 1983; Pollatsek, Lesch, Morris, & Rayner, 1992). There is extensive evidence that these functions are impaired in many dyslexics (Harm & Seidenberg, 1999; Snowling, 2000).

Although there is broad agreement that dyslexia is typically associated with impaired use of phonology, the basis of the deficit is less clear. One hypothesis is that the deficit is secondary to subtle impairments in the processing of auditory information (Tallal, 1980); another is that the deficit is limited to the processing of speech (Mody, Studdert-Kennedy, & Brady, 1997). The basic idea is that speech perception involves processing a complex, rapidly changing auditory signal. Impairments in the capacity to process this information (because of either a speech-specific or a general auditory deficit) would be expected to interfere with the development of the phonological representations that are critical to reading. The auditory-processing hypothesis gains support from studies that have identified this type of deficit in some dyslexics (Reed, 1989); the speech-processing hypothesis gains support from studies in which dyslexics demonstrated impaired processing of speech but not other auditory information (Mody et al., 1997).

It is important to note, however, that many developmental dyslexics perform normally on tests of both auditory and speech processing. For example, there have been numerous studies of the perception of consonants in nondyslexic and dyslexic individuals (de Weirdt, 1990; Nittrouer, 1999; Werker & Tees, 1987). These studies involved assessing listeners' capacity to perceive the differences between stimuli such as /pæt/ and /bæt/. The studies have found that dyslexic children whose performance on measures of phonological knowledge is impaired exhibit normal categorical perception of phonemes (Joanisse, Manis, Keating, & Seidenberg, 2000). These data point to an information processing deficit that has a significant, debilitating effect on learning to read but little impact on speech perception or other uses of language. As we have noted, segmental phonological information is critical for reading in alphabetic orthographies; it develops in part through exposure to print, and may be less crucial to the perception of spoken language. Thus, the effects of a mild information processing deficit might be manifested only in the reading context (Harm & Seidenberg, 1999).

In contrast, deficits in speech perception and auditory processing have been reliably observed in a subset of dyslexics who exhibit impairments in the use of spoken language; these children are often said to have developmental language impairment, or developmental dysphasia (Joanisse et al., 2000; Tallal, 1980; Werker & Tees, 1987). Whether dyslexia that involves a phonological deficit and developmental language impairment derive from a common underlying impairment varying in severity is also the focus of ongoing research (D. Bishop, 1997).

Other Possible Causes

Reading is a complex task involving several cognitive capacities. Impairments in any of these capacities could in principle interfere with reading. Moreover, there could be variability among dyslexics with respect to etiology; although phonological deficits are very prominent in dyslexics, there could be subgroups with other deficits (or multiple deficits). Two possibilities have been the focus of considerable research.

Visual impairments

One hypothesis is that some manifestations of dyslexia are secondary to impairments in the processing of visual information. Indeed, visual processing was the central feature of dyslexia described by Orton (1925), who hypothesized that failure to achieve normal hemispheric dominance causes dyslexics to confuse letters such as *b* and *d*. Explaining dyslexia as a visual deficit has been the standard lay theory of dyslexia, despite a relative lack of evidence (Vellutino, 1979).

Interest in a visual explanation has been revived by studies more closely tied to current theories of vision. Several studies have reported that some dyslexics exhibit impairments in visual processing that are functions of the dorsal visual pathway in the brain, the *where* system (see Ungerleider & Mishkin, 1982). This system is dominated by input from magnocellular cells in the lateral geniculate nucleus, and plays an important role in the detection of transient visual information (e.g., rapid changes in illumination, motion detection). Eden et al. (1996) reported a brain-imaging study in which a small sample of dyslexics was found to be impaired in judging the relative velocities of visual stimuli; they also exhibited abnormal activation in area V5/MT, part of the magnocellular system. However, the overall evidence for a fundamental deficit in the visual system remains in doubt. Other careful studies have failed to observe the hypothesized impairment (Hayduk, Bruck, & Cavanagh, 1996). Nor is it known how the visual deficit relates to the phonological impairment identified in many other studies. The dyslexics in the study by Eden et al. were also impaired on a nonword reading task, an indication of an impairment in phonological processing. Stein and Talcott (1999) reviewed other evidence for the magnocellular deficit hypothesis, which is the focus of considerable controversy (see chapters in Willows, Kruk, & Corcos, 1993). It is fair to conclude that although further research may confirm the existence of a type of dyslexia that arises from magnocellular processing deficits, the current evidence suggests that visual impairments by themselves are a very small part of dyslexia (Fletcher, Foorman, Shaywitz, & Shaywitz, 1999).

Developmental delay

Children with phonological dyslexia exhibit a characteristic atypical developmental pattern: They read significantly below grade level, their knowledge of phonological structure is poor, and they have difficulty sounding out unfamiliar words. Some research has identified a smaller group of dyslexics who do not fit this pattern (Castles & Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Murphy & Pollatsek, 1994; Stanovich, Siegel, & Gottardo, 1997). They also read significantly below grade level, and their phonological knowledge is also below grade level, but their levels of reading achievement and phonological knowledge are more closely matched than among children in the larger group. Unlike phonological dyslexics, their performance is very similar to that of younger children learning to read normally. Thus, they exhibit a general developmental delay in reading acquisition, rather than an overtly aberrant developmental trajectory. This delay may arise from several factors, including environmental ones (e.g., insufficient reading experience, ineffective teaching methods). However, in cases in which these environmental factors can be ruled out, several endogenous factors may produce this pattern. Such factors may include a general learning impairment, a limitation on the brain resources that are recruited for reading, or an impairment that affects the representation of orthographic rather than phonological structure (Harm & Seidenberg, 1999; Manis et al., 1996; Snowling, 2000). The possible contributions of these factors to what is likely to be a heterogeneous subgroup of dyslexics are not as yet well understood, however.

Summary

A considerable body of evidence supports the phonological-deficit hypothesis, allowing research to focus on specific questions about the nature of this deficit and ways it can be remediated. At the same time, there is growing evidence that dyslexia may have multiple causes, which may require different types of intervention, and that the causes may have different effects in the case of different writing systems. Although research has identified a narrow range of possible causes, basic questions about their frequencies of occurrence and co-occurrence, how they affect reading, and whether they give rise to different patterns of behavioral impairment remain to be determined. Answering these questions is essential to developing effective procedures for identifying dyslexic children and remediating their problems. Given the research, it appears that three main elements are necessary for reading intervention with dyslexics: (a) phonological-awareness training, (b) systematic phonics instruction that is linked to spelling, and (c) oral reading practice with *decodable* texts (i.e., texts that include only words using the accumulating set of letter-sound correspondences that have been taught).

SKILLED READING

Although our focus is on learning to read, we now examine the end point of learning to read, skilled reading. We begin by discussing research from cognitive psychology and then move to recent findings from cognitive neuroscience that are relevant for understanding reading. One emergent trend in cognitive psychology is the development of formal models implemented as computer programs that simulate behavior. In the present section, we discuss some such models that address various aspects of reading.

The View From Cognitive Psychology

Within cognitive psychology, there has been widespread interest in the processes associated with skilled reading. Cognitive psychologists have been extremely interested in how words are recognized, how eye movements are controlled in reading, how text is comprehended, and a variety of other issues. In 1879, Wilhelm Wundt established the first laboratory of experimental psychology, in Germany, and this event resulted in considerable interest in language processing (Blumenthal, 1970). One of the topics that received particular attention in the early days of experimental psychology was reading. This early interest reached its peak with the publication of Huey's (1908) classic work *The Psychology and Pedagogy of Reading*. The kinds of questions asked by Huey and his contemporaries, and covered in his book, parallel the kinds of questions addressed in modern textbooks on the psychology of reading (Crowder, 1982; Crowder & Wagner, 1992; Just & Carpenter, 1987; Perfetti, 1985; Rayner & Pollatsek, 1989). Huey was keenly interested in the mental activities involved in reading. However, with the onset of the behaviorist revolution in 1913, research on mental processes in reading ceased. A number of psychologists who had previously been interested in cognitive processes during reading turned to the burgeoning field of test development, and worked to develop tests to measure reading ability.

The reemergence of cognitive psychology in the mid-1960s resulted in widespread interest in reading once again. In the early 1970s, reading was viewed as a psycholinguistic guessing game (Goodman, 1970) or a hypothesis-testing activity (Levin & Kaplan, 1970), and tenets such as "reading is only incidentally visual" were espoused. According to this view, readers engaged in a cycle of activity in which they generated a hypothesis about what the next word would be, moved their eyes to that word, quickly confirmed their hypothesis, and then generated a hypothesis about what the next word would be. Obviously, processing was viewed as being largely contextually driven. Also, this approach suggested that there was a bottleneck during skilled reading at the stage of getting visual information into the processing system. A large amount of research on skilled reading has led to the replacement of this hypothesis-testing view by one in which the processing activities involved in reading occur very rapidly, so that the information needed for reading gets into the processing system very quickly. Thus, there is no bottleneck at the visual input stage. Furthermore, although context has an important effect on interpreting meaning, skilled readers identify words quickly with little help from context. It is readers of lower skill who rely on context to support word identification (Perfetti, Goldman, & Hogaboam, 1979; Stanovich, 1980). Two lines of research have been very influential in shaping current views about skilled reading: research on eye movements during reading and on word identification. We discuss these two topics, and then issues related to comprehension.

Eye movements in reading

Although people have the phenomenological impression that when they read their eyes glide smoothly across the page, this impression is an illusion. In fact, the eyes make rapid movements separated by periods of time when they are relatively still (called *fixations*). These fixations typically last about 200 to 250 ms, and it is during these periods that people acquire information from the text. During the actual movements of the eyes (called *saccades*, which typically cover about eight to nine letter spaces and last about 20–40 ms), vision is suppressed so that no new information is acquired. Reading is thus like a slide show in which the text is on for about a quarter of a second and then off for a brief period of time while the eyes move. In addition to making forward-moving saccades, skilled readers move their eyes backward in the text to reread material about 10 to 15% of the time; these *regressions* are often driven by breakdowns in the comprehension process.

The reason readers move their eyes so frequently has to do with acuity limitations in the visual system. Because acuity is best in the center of vision (the *fovea*), people move their eyes so as to place the text they want to process on the fovea. Outside the fovea, acuity drops off markedly in parafoveal and peripheral vision, where the anatomical receptors are not able to discriminate the fine details of the letters making up the words. Some classic research (McConkie & Rayner, 1975; Rayner, 1975; Rayner & Bertera, 1979) using an *eye-contingent display-change* paradigm, in which readers' eye movements were monitored by a highly accurate eye-tracking system and changes in the text were made contingent upon where the reader was looking (see Fig. 4), demonstrated that the *perceptual span* (or region from which useful information is acquired) is restricted to an area extending from 3 or 4 letter spaces to the left of fixation to 14 or 15 letter spaces to the right of fixation for readers of English. Information used to identify words is typically restricted to no more than 7 to 8 letter spaces to the right of fixation, with more gross information (such as the length of upcoming words) acquired out to 15 letter spaces.

The consequence of these acuity and perceptual-span limitations is that skilled readers fixate on about two thirds of the words in text; the words that are typically skipped are short words and words that are highly predictable from the preceding context. But even though words are not directly fixated, there is evidence that they have been processed (as fixations preceding and following skips have inflated durations). Two other facts are highly relevant for the current discussion (see Rayner, 1998, for further detail). First, the information needed for reading gets into the processing system very quickly. As long as the text is available for 50 to 60 ms before a masking pattern appears to obliterate it, reading proceeds quite normally. Second, although readers are not consciously aware of their eye movements, how long the eyes remain fixated on a word is very much influenced by the ease or difficulty of understanding that word. Thus, for example, low-frequency words are fixated longer than high-frequency words. The conclusion that follows from all of this evidence is that readers are not engaging in all sorts of guessing activities, but rather are efficiently and quickly (at an unconscious level) processing the text. Indeed, all the letters in a word are being processed during word identification, as we discuss in the next section.

```
Normal Text:

John composed a new song for the children

Moving Window:

xxxx xxxxxxed a new song for txx xxxxxxxx
                    *

xxxx xxxxxxxx x new song for the chxxxxxx
                         *

Boundary:

John composed a new tune for the children
            *

John composed a new song for the children
                     *
```

Fig. 4. Examples of eye-contingent display-change paradigms. The top line shows a line of normal text. In the moving-window example, a window of readable text (extending 9 letter spaces to the left and right of fixation, indicated by the asterisk) is available on each fixation (with letters outside the window replaced by *x*s). Two consecutive fixations are shown. In the boundary example, the word *tune* is initially present in the text, but *tune* changes to *song* when the reader's eye movement crosses an invisible boundary location (the *w* in *new*). Adapted from Rayner (1998).

We conclude this section with three final observations. First, beginning readers' eye movements are quite different from those of skilled readers (Rayner, 1986). Beginning readers fixate virtually every word (and make more than one fixation on many words). Thus, their saccades are much shorter (around three letter spaces) than skilled readers'. Furthermore, their average fixation durations are much longer (between 300 and 400 ms) than skilled readers', and they regress much more frequently (so that up to 50% of their eye movements are regressions). Their perceptual span is also smaller than that of skilled readers (see Fig. 5). Basically, their eye movements reflect the difficulty they have encoding the words in text. Second, research on skilled readers shows quite clearly that phonological

Skilled reader:

The beautiful /black horse was run/ning
*

Tbc hconfrtnt /**black hor**ac vcr rnu/uimp
*

Tbc hconfrtnt htosb /**horse was run**uimp/
*

Beginning reader:

The little /boy sat in/ the big car
*

Tbc trlltc /**boy sa**f rm/ fbc hrq scn
*

Tbc trlltc dcp /**sat in t**bc/ hrq scn
*

Fig. 5. Illustration of the perceptual span for skilled readers and beginning readers. The text between the two slashes on each line represents the size of the perceptual span for a given fixation. The asterisks indicate fixation location. For each kind of reader, the top line illustrates a fixation and the total perceptual span. The next two lines illustrate more specifically, for two successive fixations, which letters are identified (in boldface) and which letters are not identified (not in boldface). Some information, such as word length and gross featural information, can be obtained from unidentified letters inside the perceptual span.

+	+	+	Fixation point
word	d	orwd	Stimulus display
d #### k	d # k	d #### k	Response choices

Fig. 6. Sample display sequences in the word-superiority-effect paradigm. On the left is an example of the display sequence when the target stimulus is a word (in this case, *word*). First, a fixation point is presented. It is followed by a very brief presentation of the target word (the stimulus display), which is immediately followed by a mask (####) and two response choices (*d* and *k*). The subject has to choose which of the response choices was present in the stimulus. In the middle is an example of a display sequence with a single-letter target stimulus (in this case, *d*). On the right is an example of a display sequence with a nonword target stimulus.

codes are activated for words very early in eye fixations (Pollatsek et al., 1992; Rayner, Sereno, Lesch, & Pollatsek, 1995). Finally, there are now computer simulation models (Reichle, Pollatsek, Fisher, & Rayner, 1998) that do a very good job of predicting where readers fixate and how long they fixate.

Word identification

An important issue with respect to how words are read deals with whether they are processed as wholes (in parallel) or letter by letter (serially). More than 100 years ago, Cattell (1886) addressed this issue by asking people to report what they saw when words and letters were briefly exposed. In fact, they were better able to report words than letters. These results were used by educational reformers to advocate whole-word teaching methods. However, when Reicher (1969) and Wheeler (1970) replicated this finding with an improved experimental design, the results did not support whole-word instruction. The characteristics of their paradigm are shown in Figure 6. Basically, a word, single letter, or nonword letter string was presented very briefly (about 25–40 ms) and followed immediately by a masking pattern that would interfere with any extended processing of the stimulus after its offset. In addition, two letter choices were presented: One was the correct letter (in the word and nonword conditions, the letter that had been previously shown in the position indicated), and the other was a letter that had not been presented. Notice, however, that in the word condition, this incorrect alternative, if substituted in the word in the position indicated, always resulted in a different word (e.g., in Fig. 6, the incorrect alternative, *k*, also made a word if substituted for *d*). Reicher and Wheeler found that responses were more often correct in the word condition than in the other conditions. Thus, a letter is better identified when it is embedded in a word than when it is presented in isolation or in a nonword. This result, called the *word-superiority effect*, suggests that Cattell's phenomenon is real: Letters in words are identified more accurately than letters in isolation.

The phenomenon forces two conclusions. First, the serial, letter-by-letter view of word recognition cannot be correct: If this view were correct, readers would have been more accurate with single letters than words given the limited processing time. Second, all the letters in the word must have been processed, as readers were able to identify correct letters at all positions with equal accuracy. This latter point has implications for reading instruction because it indicates that all the letters in a word need to be processed in order for the reader to build a specific representation of the word that can be accessed quickly and accurately. Although memorizing the shapes of words at the beginning of reading may get children started reading, it is not enough for reading development to continue (Ehri & Wilce, 1983).

In general, the word-superiority effect has been taken as evidence that all of the letters in short words are processed in parallel. The effect ultimately led to the development of powerful computer simulation models designed to account for the results. These initial models, called the interactive activation model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982) and the verification model (Paap, Newsome, McDonald, & Schvaneveldt, 1982), were the forerunners of even more elegant and powerful connectionist models (such as Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989) that we discuss in Using Connectionist Models to Understand Reading and Dyslexia.

A second general issue regarding word identification is the extent to which phonological (or speech-based) codes are involved in identifying words. In principle, the meanings of words could be identified in two ways: either directly from print (traditionally termed *direct access*) or by computing a letter string's phonological code and using that information to access meaning (*phonologically mediated access*). There has been a long-standing debate about which of these is more efficient. Smith (1973) forcefully argued that direct access is necessarily more efficient because it does not require the extra phonological-recoding step and because English has numerous irregularly pronounced words (*have*, *pint*, etc.). His observations had considerable impact on educational practice, lending support to whole-word (and later, whole-language) approaches.

The problem with direct access, however, is that, unlike the mapping between spelling and sound, the mapping between spelling and meaning is largely arbitrary (Van Orden, Pennington, & Stone, 1990) and thus difficult to learn. Moreover, consider what happens when a beginning reader encounters an unfamiliar word. The direct-access mechanism cannot operate because the letter string has not been encountered before and thus the association between form and meaning has not been established. However, if the child can phonologically recode the letter string ("sound it out"), it can be matched to knowledge of the word derived from spoken language. Thus, phonological recoding provides a basis for generalization, as well as an important self-teaching mechanism (Jorm & Share, 1983). The debate about the extent to which word reading is phonologically mediated clearly parallels (and indeed contributed to) the debate concerning the extent to which reading instruction should emphasize phonics.

Most contemporary theories of word reading assume that both direct and phonologically mediated mechanisms are available to skilled readers (see Fig. 7), but they make different assumptions about the division of labor between them (Frost, 1998; Seidenberg, 1995). Some theories assume the primacy of the direct pathway (Coltheart, 1978), others the primacy of phonological recoding (Berent & Perfetti, 1995; Van Orden et al., 1990). In Paap and Noel's (1991) influential model, processing is attempted in the two pathways in parallel, with a race between them. Which pathway "wins" for any given word depends on word factors (such as familiarity and spelling-sound consistency), reading skill, and the nature of the writing system (how directly and consistently it represents phonological information). In Harm and Seidenberg's (2001) recent model, both pathways jointly determine the activation of meaning (see Using Connectionist Models).

There is now a large body of evidence that phonological information plays an important role in word reading, even among highly skilled readers (Frost, 1998) and for nonalphabetic writing systems such as Chinese (Perfetti & Zhang, 1995). We have already noted that eye movement experiments have demonstrated that phonological codes are activated very early in an eye fixation. Other compelling evidence comes from studies by Van Orden (1987; Van Orden, Johnston, & Hale, 1988), who devised a clever way to diagnose the activation of phonology. Subjects were presented with a question (e.g., "Is it a flower?") and then had to read a target word (e.g., *rose*) and decide if it is a member of the designated category. On critical trials, the target was a homophone of a category exemplar (e.g., *rows*). On a significant number of such trials, subjects incorrectly identified the word as a member of the category. Moreover, such false positive responses also occurred for nonword targets that sounded like words (e.g., article of clothing: *sute*). These responses would not have occurred unless subjects had phonologically recoded the letter strings. Similar results have been obtained in studies of several other writing systems (Frost, 1998). Thus, phonological recoding plays a much more prominent role in skilled reading than Smith (1973) asserted. This is among the most important findings in contemporary research on reading, and it strongly suggests the achievement of reading skill depends in part on learning to use phonological information efficiently.

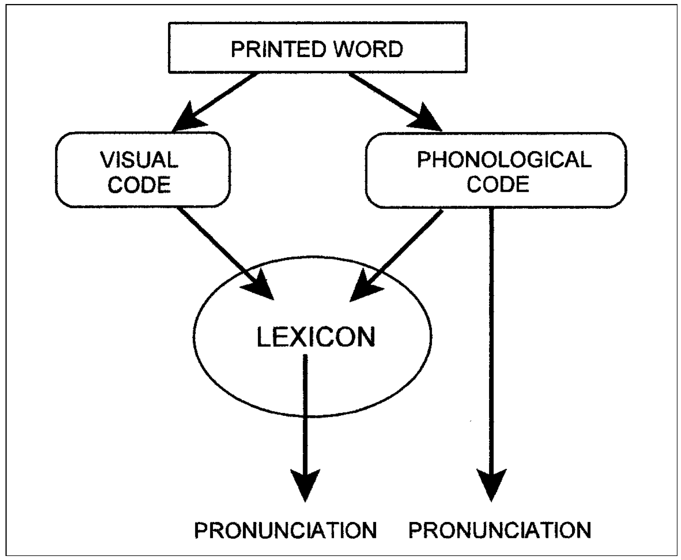

Fig. 7. A simple dual-route model of word recognition. The arrow from the printed word to the visual code represents the direct route to the lexicon, whereas the arrow from the printed word to the phonological code represents the route to the lexicon via grapheme-phoneme correspondences. The arrow directly from the phonological code to pronunciation reflects the fact that nonwords can be pronounced.

Reading comprehension

Whether reading uses just those processes that serve spoken language or requires something more turns out to be a difficult question. Reading comprehension clearly depends on spoken language comprehension. Correlations between spoken language and reading comprehension are modest early in learning to read (Curtis, 1980) but, as noted earlier, increase with the development of reading skill (Sticht & James, 1984), reaching .90 for adult samples (Gernsbacher, 1990). Thus, reading comprehension has little variance unique to reading for adults, but shows both variance shared with listening comprehension and variance unique to reading among children. This pattern of correlations indicates that reading comprehension skill approaches listening comprehension skill as printed word identification is mastered.

Reading comprehension involves a number of different interacting processes that have been the target of much research. Some of this research has emphasized the guidance given to comprehension by higher-level sources of knowledge. For example, readers are sensitive to the causal relations among characters' actions as they read a story (Trabasso & van den Broek, 1985). They may also use a wide range of knowledge outside the text to guide comprehension in other ways, including by making inferences (Graesser, Singer, & Trabasso, 1994). It is clear that readers do more than merely comprehend sentences when they read. However, some general models of comprehension describe in detail how the comprehension of text can be built up over the reading of successive words and sentences, from the bottom up (Kintsch, 1988, 1998; McKoon & Ratcliff, 1992; Myers & O'Brien, 1998). Thus, comprehension includes guidance from knowledge outside the text, but even this influence can be understood in part by how the meanings of words actually read in the sentence trigger such knowledge. Even reading comprehension begins with the word.

Accordingly, accessing word meaning in context, parsing sentences, and drawing inferences are all part of the overall process of comprehension. In addition, the skilled reader monitors his or her comprehension to verify that the text is making sense. When readers have problems in comprehension, the source might be any of these processes. Indeed, the interdependence among the components of comprehension means that multiple problems are likely to be observed in such cases and that finding a single cause of comprehension failure, as a general case, is unlikely. For example, because the higher levels of processing rely on output from lower levels, an observed problem in text comprehension can also result from lower-level processes, including word identification, basic language processes, and processing limitations.

The interplay among these lower-level factors can be complex. For example, differences in basic language skill lead to individual differences in comprehension, and less skilled readers show a wide range of problems with syntax. The question is whether such problems arise from a syntactic-processing deficit or from some other source that affects performance on syntactic tasks (such as working memory limitations, lack of practice, or lexical processing limitations). Research with children (Crain & Shankweiler, 1988) and adults (Carpenter, Miyake, & Just, 1994) suggests that syntactic parsing problems can arise from processing limitations rather than from problems with syntax itself. Comprehension difficulties may be localized at points of high processing demands—whether from syntax or something else. If this analysis is correct, then the problem is not intrinsic deficits in syntax, but the processing capacity to handle complexity. More generally, the hypothesis that working memory factors produce individual differences in comprehension has received wide support over years of research (Baddeley, 1979; Just & Carpenter, 1992; Perfetti & Lesgold, 1977; Shankweiler & Crain, 1986). It is clear that among children as well as adults, working memory factors constrain comprehension of both spoken and written language.

An interesting view on individual differences is the *structure-building framework* (Gernsbacher, 1990), which frames comprehension skill around the assumption that readers, in constructing a coherent framework for a text, activate and enhance relevant concepts while suppressing irrelevant concepts. According to this approach, people with poor reading skills have deficient suppression mechanisms. Consider, for example, the sentence "He dug with the spade." The final word in this sentence has two meanings, but only one fits the context of the sentence. However, when adults are asked to decide whether a word is related to the meaning of the sentence, their decisions are initially slow for *ace* (related to the inappropriate meaning of *spade*). In other words, both appropriate and inappropriate meanings may be activated at first. If the amount of time between reading the sentence and seeing *ace* is increased, however, skilled readers show no delay in rejecting it (i.e., they suppress the irrelevant meaning), but less skilled readers continue to react slowly to *ace,* as if they have not completely suppressed the irrelevant meaning of *spade*. A failure to use context is not what is involved here. Research with children found that less skilled readers use context in word identification at least as much as and perhaps more than do skilled readers (Perfetti, 1985; Stanovich, 1980). However, either a failure to suppress irrelevant information, an insufficient level of specific and reliable knowledge about word forms and meanings (Perfetti & Hart, in press), or both can lead to comprehension failures.

The complexity of text comprehension implies several possibilities for processing failure beyond those already discussed. There are also higher-level skill differences in text comprehension. For example, problems in making inferences have been the target of much research. Oakhill and Garnham (1988) summarized evidence suggesting that less skilled readers fail to make a range of inferences. When skill differences in inferences are observed, their uniqueness—that is, whether they occur in the absence of differences in lexical, working memory, or general language processes—is seldom clearly demonstrated. However, there has been some success in identifying a small percentage of children whose problems can be considered comprehension-specific, although highly general across reading and spoken language (Stothard & Hulme, 1996).

Another example of a high-level contributor to comprehension problems is comprehension monitoring (a reader's implicit attempt to ensure a consistent, meaningful understanding). Skilled readers can use the detection of a comprehension breakdown (an apparent inconsistency) as a signal for rereading and repair. Less skilled readers fail to engage this monitoring process (Baker, 1984; Garner, 1980). However, such differences may not be independent of the ability to construct a simple understanding of the text (Otero & Kintsch, 1992). Because comprehension monitoring, like inference making, both contributes to and results from the reader's text representation, it is difficult to attribute comprehension problems uniquely to failures to monitor comprehension, as opposed to more basic comprehension failures.

For comprehension to succeed, readers must import knowledge from outside the text. Thus, a powerful source of individual differences in comprehension skill is access to knowledge needed for a given text (Anderson, Reynolds, Schallert, & Goetz, 1977). However, readers of high skill compensate for lack of knowledge to some extent (B.C. Adams, Bell, & Perfetti, 1995). It is the reader who lacks both knowledge and reading skill who is assured failure. Moreover, the deleterious effect of low reading skill (and its motivational consequences) on learning through reading creates readers who lack knowledge of all sorts.

Perhaps nothing is so important to successful reading comprehension as practice, by which we mean repeated engagements with reading texts of various types. Reading itself increases familiarity not only with words but also with text structures and written syntax, which are not identical to the typical structures and syntax of spoken language. Thus, continuing development of reading skill as a result of initial success at reading—and the parallel increasing failure as a result of initial failure—is undoubtedly a major contributor to individual differences in reading comprehension.

Implications for learning to read

As we noted at the outset of this section, the view of skilled reading has changed dramatically over the past 30 years. Whereas skilled reading was once considered a guessing game because of bottlenecks in the processing system, it has become quite clear that skilled readers are able to quickly process the visual information in the text, and that it is more efficient to process what is there than to make guesses about what may be there. In addition, a considerable amount of research suggests that phonological codes are intimately involved in skilled reading. Whereas it was once thought that phonological processing in reading was simply a carryover from the way children are taught to read (orally before silently), it now appears that phonological codes are activated very early in processing words and that this information is used in both accessing the meanings of words and remembering information in the text. What all of this suggests is that instruction that helps children efficiently and quickly understand words, and that provides an analytic strategy for learning new words, should provide the most effective way to become a skilled reader.

The research on comprehension has less precise implications for learning to read. It does suggest that a combination of (a) simple comprehension procedures closely linked to word processing and syntax and (b) more complex knowledge-driven processes is characteristic of skilled comprehension. Various ideas about comprehension instruction in the context of reading have been proposed and have been the target of active research. However, there is little in the basic research on comprehension nor in instructional research to give strong guidance on comprehension instruction.

The View From Cognitive Neuroscience

Although modern brain-imaging work is still in its infancy, methods such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) have provided new and converging information about the functional neuroanatomy of reading. These imaging methods provide spatial information on a centimeter or even millimeter scale, but with limited temporal information. Questions about time course are better addressed by event-related potential (ERP) methods. Although the standard brain-imaging question may appear to be "What lights up in the brain when words are read?" the potential of brain-imaging research goes well beyond this. For example, do studies yield evidence for the phonological processes of word identification that have proved so important for understanding reading? What do imaging studies have to say about the reading problems identified in dyslexia research?

Brain imaging

Neuroimaging studies of reading generally require comparisons between images made during the performance of a reading task and those made during baseline conditions. A simple comparison that has provided basic data on reading is one between reading aloud a single word and looking at a small fixation cross. This comparison has identified regions that show greater activation during the reading task. In many cases, the regions are also activated during other kinds of tasks. For example, primary motor cortex is activated during reading because it is involved with movements of the mouth required by oral reading. Identifying areas that play a more distinctive role in reading itself requires other comparisons.

Research following this general approach has identified brain regions that play some role in word reading (see Fiez, in press, for a review). Imaging studies have sought to link specific orthographic, phonological, and semantic components of word identification (Crosson et al., 1999; Pugh, Shaywitz, Shaywitz, & Shankweiler, 1997) to specific locations in inferior frontal cortex, the left temporoparietal cortex, and the left basal temporal cortex (near the occipital-temporal boundary). For example, Fiez, Balota, Raichle, and Petersen (1999) found that a left frontal region responded differentially to words with consistent spelling-to-pronunciation mappings and words with inconsistent mappings. Thus, these three areas, illustrated in Figure 8, appear to provide a major part of the functional neu-

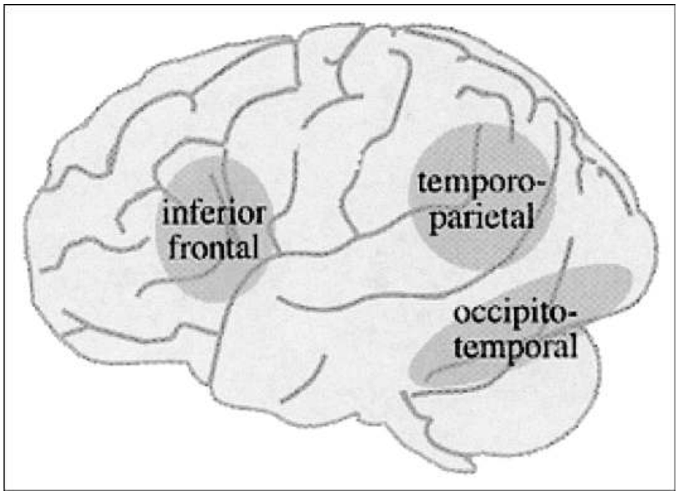

Fig. 8. A simple schematic of some of the left-hemisphere brain areas that are involved in word reading (based on Fiez, in press). (Some right-hemisphere areas are also involved in reading.) Research suggests posterior areas (occipitotemporal) may include structures specifically involved in orthographic processing of printed words (i.e., a visual word-form area). Both left inferior frontal and temporoparietal regions play a role in word reading that involves phonological processing.

roanatomy underlying the knowledge components (orthographic, phonological, and semantic) that are needed in word reading. We now consider briefly what has been learned about each source.

The visual areas in the occipital cortex that are used for object recognition are an obvious candidate for supporting orthography in the brain. In examining this hypothesis, researchers have focused comparisons on activations associated with reading words versus looking at pictures and on activations associated with reading different kinds of letter strings (e.g., words, pseudowords, and strings of letters). The search for an area that is dedicated to printed words (a *word-form* area) has led to some strong candidates, especially in an area near the occipitotemporal border, the left middle fusiform gyrus. This area responds differently to nonwords, pseudowords, and words (Fiez & Petersen, 1998). In patients with lesions in occipitotemporal areas, severe disturbances in ability to read words as wholes, with a reliance on letter-by-letter reading (pure alexia), has been reported (Patterson & Lambon Ralph, 1999).

As we have emphasized, the conversion of an orthographic form into a phonological form is a central part of reading, and how the brain carries out this task is of great interest. Furthermore, the inability to read pseudowords—a process that relies on this conversion process without the aid of word meaning—has become a marker for phonological dyslexia (Coltheart, Curtis, Atkins, & Haller, 1993). Studies of patients have identified two brain regions where lesions lead to deficits in phonological decoding—the left inferior frontal lobe and the temporoparietal cortex. Lesions in one or both of these areas are associated with difficulty in reading pseudowords (Fiez & Petersen, 1998; Patterson & Lambon Ralph, 1999). Patients with these lesions tend to read words relatively well (compared with pseudowords), as if they are able to use a stored lexicon that remains intact with these lesions. Recent evidence from direct electrical stimulation of the temporoparietal region produces an interesting convergence with the data from patients. The ability of normal readers to name pseudowords, a signature task for sublexical processing, is disrupted by stimulation in this region, but their ability to name real words is not (Simos et al., 2000). Also, frontal regions have shown greater activation for pseudowords than for real words in some studies (Fiez & Petersen, 1998). Thus, both left frontal and temporoparietal regions are active in reading in tasks that require or encourage phonological processing (Demonet, Fiez, Paulesu, Petersen, & Zatorre, 1996). However, whether sublexical and lexical processes can be neatly separated remains uncertain.

In discussing dyslexia, we noted the pervasive extent of behavioral evidence for a phonological-processing deficit, and imaging studies provide a convergent picture (Georgiewa et al., 1999; Pugh et al., 1997; Rumsey et al., 1999; Shaywitz et al., 1998; Small, Flores, & Noll, 1998). In particular, dyslexics show lower levels of activation in both left frontal and temporoparietal regions compared with skilled readers (Rumsey et al., 1999; Shaywitz et al., 1998). Recent evidence adds an intriguing possibility that the processing problems of dyslexics may depend on the writing system. For example, a phonological deficit may have more of an impact for a reader of a deep orthography (e.g., English) than for a reader of a shallow orthography (e.g., Italian), in which spelling-sound correspondences are highly consistent. Paulesu et al. (2001) reported a brain-imaging study of Italian, English, and French dyslexics. All three groups were impaired on tests of reading and phonology and showed reduced activity in left-hemisphere regions implicated in reading. However, the Italian dyslexics performed better on tasks involving the pronunciation of words and nonwords. The phonological deficit common to all dyslexics in all three languages appears to have had less of an impact in Italian because it is a shallow orthography.

Finally, both left frontal (Fiez, 1997) and basal temporal regions (Price, 1998) have been identified as candidates for semantic processing (which has been studied using tasks that require the retrieval of word names and concepts). Different kinds of dyslexia have been linked to these two regions: developmental phonological dyslexia to left frontal and temporoparietal regions, and acquired surface dyslexia to basal temporal lesions. Surface dyslexics, who experience reading problems as a result of brain damage, have problems with reading words lexically, as whole words (as opposed to reading sublexical units). Thus, their problem is manifest on words that contain inconsistently pronounced spelling patterns, or so-called irregular words (e.g., *choir*). Patients with basal temporal lesions tend to show the same problem when reading words, as well as a more general deficit in picture naming (Patterson & Lambon Ralph, 1999). Although overlapping regions in the basal temporal area are activated during picture and word naming, there also appears to be differential activation (across frontal vs. posterior areas of the fusiform gyrus) for naming pictures versus naming words (Moore & Price, 1999). Interestingly, frontal and temporal regions found to be activated in studies of reading alphabetic systems overlap with those found to be activated in reading Chinese (Chee, Tan, & Thiel, 1999; Tan et al., 2000).

ERPs

Complementary to the spatial information from fMRI and PET are the time-sensitive recordings obtained from ERPs, measures of electrical activity from electrodes placed on the surface of the head. The voltages associated with brain activity vary in both polarity and magnitude over time, resulting in a series of electrical peaks and valleys that can reflect the dynamics of reading over a few milliseconds. ERP evidence has provided information about the time course of events associated with reading, confirming ideas about the rapidity of orthographic and phonological processing. Word-level processes are observed within 130 to 200 ms after the onset of a word (Posner, Abdullaev, McCandliss, & Sereno, 1999; Posner & DiGirolamo, 2000; Rudell & Hua, 1997; Sereno, Rayner, & Posner, 1998). Orthographic processes are observed within 200 ms in occipital and occipitotemporal regions, and mainly in the left hemisphere (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Martin-Loeches, Hinojosa, Gomez-Jarabo, & Rubia, 1999), consistent with the idea that learned forms of the writing system acquire a functionally distinct status within the visual processing system. For orthographic inputs that allow phonological processing, a second stage of processing is reached in temporal areas within 350 ms. For inputs that are processed to the semantic level, anterior temporal and frontal regions show their roles within 400 to 450 ms.

Thus, various methods, including eye movement, brain-imaging, and ERP studies, converge on a coherent picture of word reading as a rapid process from graphic input to phonological and meaning outputs distributed across functional brain regions.

Implications for learning to read

The knowledge gained from neuroscience methods is becoming informative with respect to questions about skilled reading and reading problems. The big question for learning to read, how the brain supports the acquisition of reading skill, remains to be addressed. However, there are studies that illustrate the promise of neuroscience methods for showing how the brain responds to training. For example, repeated practice affects ERP components, presumably reflecting gains in efficiency through specific learning (Rudell & Hua, 1997). Moreover, such learning can actually influence brain development and neuronal connectivity. A recent fMRI study found a thicker band of callosal connective fibers between parietal lobes for literate than for illiterate adults (Castro-Caldas et al., 1999). A study designed to shift an acquired dyslexic from a whole-word reading strategy to a phonological strategy found that activation patterns in the brain changed following the intervention (Small et al., 1998). In both studies, learning apparently produced an alteration in brain circuitry, and there is the implication that neuronal connectivity remains plastic into adulthood.

We can illustrate the effect of learning on brain circuitry for an ability assumed to be central to learning to read—phonological processing. Castro-Caldas et al. (1999) examined oral language processing in illiterate adults in Portugal (this group was fully functional socially; illiteracy was widespread in rural portions of Portugal until recently). The key comparisons concerned performance and brain activations for the literate versus illiterate participants when they repeated words or pseudowords spoken to them. With real words, the literate and illiterate participants performed comparably and showed similar brain-activation patterns. But with pseudowords, the illiterate participants performed more poorly than the literate participants, and their brain-activation patterns were not the same. Castro-Caldas et al. suggested that literacy acquired during childhood affects the functional organization of the brain. Cognitive neuroscience methods promise to be useful for investigating many topics in the study of reading—the components of word identification, cross-language comparisons, the acquisition of skill, and even comprehension. There remains much to learn about the specific brain regions that support these specific processes. And there is much more to learn about how the brain reorganizes itself during learning to read.

USING CONNECTIONIST MODELS TO UNDERSTAND READING AND DYSLEXIA

The tools available to study reading have expanded in recent years to include computational models, which are computer programs that simulate detailed aspects of how children learn to read, of skilled reading, and of dyslexia. So, for example, a model might be taught to recognize letter strings and compute their meanings or pronunciations using the same principles thought to govern children's performance. Such models complement behavioral and neuroimaging studies that have provided the main empirical evidence concerning reading. The models typically focus on components of the reading system such as eye movements (Reichle et al., 1998), pronunciation (Coltheart et al., 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), and orthographic processing (Grainger & Jacobs, 1994).

In focusing on connectionist models in this section, our goal is not to assess whether they provide better explanations of reading than other models, such as the dual-route model developed by Coltheart and colleagues (Coltheart et al., 1993, 2001). The connectionist and dual-route models account for many of the same phenomena, and the differences between them are not highly relevant to the issues discussed here. We use connectionist models to illustrate how important phenomena in word reading, learning to read, and dyslexia can be understood within relatively simple systems that learn to translate between orthographic, phonological, and semantic codes.

Connectionist models are useful for several reasons. First, they incorporate ways of thinking about how knowledge is represented, acquired, and used that may deviate from intuitive accounts of cognitive phenomena. For example, words are not represented as entries in a mental lexicon but rather as patterns of activation over units encoding orthographic, phonological, and semantic information. This notion invites reconsidering the data previously taken as evidence for other types of mechanisms. Second, connectionist models attempt to achieve theoretical generality by explaining reading in terms of basic principles of learning, knowledge representation, and information processing that govern many aspects of language and cognition. This approach is consistent with the observation that reading, a relatively recent development in human culture, relies on capacities that evolved for other purposes.

Third, the models provide a strong method for testing the adequacy of theoretical proposals. With the more informal approach to theorizing characteristic of much reading research, it is not always clear if the proposed mechanisms work in the intended ways. Connectionist models provide a unique way to test causal hypotheses about the bases of normal and disordered reading. Consider the long-standing debate about methods for teaching reading. Phonics methods assume that learning the relationship between the written and spoken forms of language is an important step in becoming a skilled reader. Whole-language methods assume that using phonological information distracts the beginning reader from the goal of learning to read for meaning; hence, the approach emphasizes instructional practices that promote the development of literacy rather than phonological decoding. There are plausible intuitive arguments for both approaches. One way to assess these competing claims is by conducting studies in which a model is trained in different ways. Modeling complements field studies by providing insight about why particular outcomes are obtained, and it allows close control over potentially confounding factors.

Basic Elements of Connectionist Models of Reading

Most connectionist models use *distributed representations*, in which spelling, sound, and meaning are represented by small sets of units that participate in many words (Hinton, McClelland, & Rumelhart, 1986). For example, a model might include units that correspond to phonetic features, and each such unit is activated for all the words that contain that sound. Like other aspects of the theoretical framework, the use of distributed representations is motivated by the desire to use mechanisms that are consistent with evidence about brain function; in this case, the use of distributed representations is consistent with the fact that large networks of neurons encode information in the brain. Connectionist models also include *hidden* units that allow the network to encode more complex mappings between orthographic, phonological, and semantic codes.

In a connectionist model, units are linked to one another to form a network; when a letter string is presented as an input, the corresponding units are activated, and this activation spreads to other units (representing phonological or semantic information). The connections between units carry weights that determine how much activation is passed along. The goal is to find weights that allow the model to perform these computations proficiently; learning means adjusting the weights on the basis of experience. The word-reading models have used a learning procedure (*backpropagation*) in which the output that the model produces for a word is compared with the correct, target pattern. Small adjustments to the weights are made on the basis of discrepancy between the two. Performance improves gradually as the weights assume values that minimize this discrepancy. Backpropagation is a kind of learning algorithm in which the output the model computes is compared with a target pattern (see Hinton, 1989, for an overview). Whether the brain uses this algorithm or others that have very similar effects is a topic of current research. Although the learning procedure used in the reading models is undoubtedly simplified, it captures basic elements of how learning occurs in this and other domains.

Behavior in connectionist networks (as in people) is determined by both constitution and experience. The reading models (see Fig. 9), for example, were constructed with the capacity to represent different lexical codes (orthography, phonology, semantics) and the capacity to learn. These representations are themselves thought to have resulted from the joint influence of biological endowment and experience. Like children, the models learn through exposure to many examples (e.g., letter patterns paired with pronunciations or meanings). The fact that words are internally structured emerges through exposure to a large ensemble of words that overlap in different ways and degrees. The models gradually pick up on this structure because it allows phonological and semantic codes to be computed more efficiently.

Insights From Connectionist Models

Connectionist models provide a new perspective on many of the issues discussed in this monograph. Here we focus on three issues that have been the focus of considerable debate among reading researchers.

How do children learn the correspondences between spelling and sound?

We noted earlier that learning about the correspondences between the written and spoken forms of words is a critical step in becoming a skilled reader. However, English is notorious for having many exception words that have irregular pronunciations (e.g., *give*, *said*, *was*, *have*, *does*). Many of these are high-frequency words that are among the first that beginning readers must master. As noted earlier, Smith (1973) argued that because of these irregularities, reading that involves

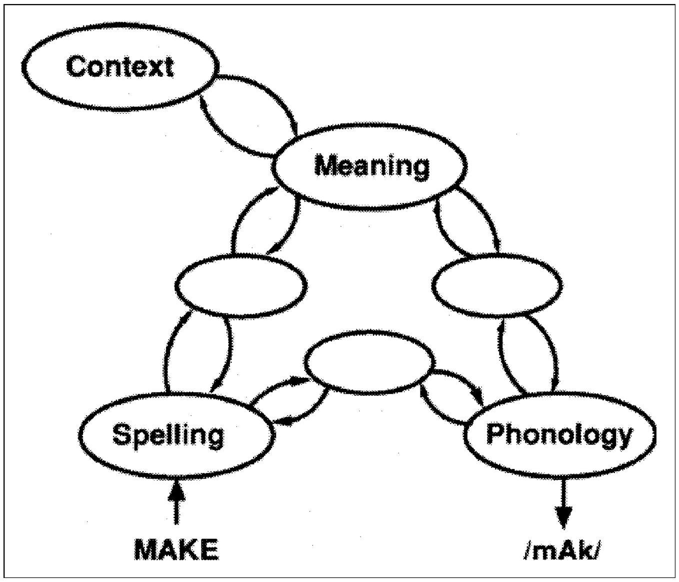

Fig. 9. The connectionist model developed by Seidenberg and McClelland (1989), who implemented the orthography-phonology pathway. Harm and Seidenberg's (2001) model includes both the orthography-phonology pathway and the orthography-phonology-semantics pathway. In both models, words are pronounced by activating a set of orthographic units, which pass activation to the phonological units along weighted connections. Meanings are computed using input from both orthography-semantics and orthography-phonology-semantics components. The unlabeled ovals represent hidden units, which allow the network to learn complex mappings between codes. From "A Distributed, Developmental Model of Word Recognition and Naming," by M.S. Seidenberg and J.L. McClelland, 1989, *Psychological Review*, *96*, p. 526. Copyright 1989 by the American Psychological Association. Reprinted with permission of the authors.

phonological recoding (i.e., translating from spelling to sound to meaning) cannot be efficient. Connectionist models suggest that this reasoning is flawed.

Seidenberg and McClelland's (1989) model learned the pronunciations of both regular words such as *gave* and exceptions such as *have* with relatively little training (at most 250 trials, for very low-frequency exceptions such as *torque*; most words were learned with many fewer trials). Acquisition is rapid because what is learned about one word (e.g., *gave*) also applies to overlapping words (*save* and *gate*). The same thing is true for exceptions: The model's performance on *have* benefits from exposure to overlapping words such as *had*, *has*, and *hive*. Thus, the same network and learning procedure are used for all words; regular and exception words differ only in the degree to which their spelling-sound correspondences overlap with those of other words. Learning the exceptions is less of a problem than Smith (1973) asserted because they are not arbitrary and the learning procedure is efficient.

How does phonological awareness develop?

Earlier we noted that there is a reciprocal relationship between the development of segmental phonemic representations and learning to read. Prereaders' knowledge of phonological structure is causally related to success in learning to read; at the same time, learning to read changes the nature of phonological representations, making them more segmental. Connectionist models provide additional insight about the mechanisms underlying the interactions between phonological knowledge and reading. Children come to the task of reading with extensive knowledge of spoken language, but their knowledge of phonological structure is relatively coarse; being able to tell that *bag* and *bat* are different spoken words can be done on the basis of nonsegmental information. Phonological representations are further shaped by children's participation in reading.

To make this point concrete, Harm and Seidenberg (1999) developed a model of the orthography-phonology mapping that was trained in two phases. The first phase, which involved exposing the model to the phonological forms of words, was meant to capture the kinds of phonological knowledge children acquire from speech. The second phase involved training the model to map from orthography to the pretrained phonological system. Learning this mapping changed the organization of phonology, promoting clearer representations of subword units such as phonemes, onsets, and rimes. The development of these representations in turn facilitated learning to read additional words.

What was crucial in the model was not having full phonemic representations prior to reading (though that would be useful) but rather having the capacity to develop such representations with reading experience. Reducing this capacity interfered with the development of subword units; thus, when the model was exposed to a word such as *gave*, there was less carryover to partially overlapping words such as *save*. Two consequences of this limitation were observed. First, the model took much longer to learn the phonological codes for words. Second, it generalized poorly; lacking knowledge of subword structures, it could not piece together the pronunciations of novel words very well. The model did not address many aspects of phonological development, and further research is needed. However, the initial results provide additional causal evidence linking the development of phonological representations and the acquisition of reading skill. Moreover, the modeling suggests that constitutional differences in the capacity to encode phonological structure may contribute to variable outcomes in learning to read. Finally, it suggests that segmental representations are closely tied to knowledge of orthography rather than speech.

Is word reading direct or phonologically mediated?

As noted earlier, there has been a long-standing debate about whether words are recognized visually (by a direct mapping between orthographic patterns and meanings) or via phonology. Harm and Seidenberg (2001) attempted to break this impasse by treating the issue as a computational one: How does a connectionist model learn to compute meanings quickly and accurately? That is, what division of labor does the model converge on, given the availability of both pathways? The answer is that Harm and Seidenberg's model pooled the input from both sources for almost all words. Given orthographic input, the semantic pattern that was computed reflected the joint effects of both pathways. This property contrasts with the independence of the orthography-semantics and orthography-phonology-semantics pathways in race models (Paap & Noel, 1991), in which meaning is accessed by the process that finishes first. The connectionist model performs more efficiently, using both pathways rather than either one in isolation; thus, it is a question not of which pathway wins the race, but rather of how the pathways cooperatively solve the problem.

Early in the model's training, semantic activation is largely driven by input from the orthography-phonology-semantics pathway. The phonology-semantics component is trained prior to the introduction of orthography on the view that prereaders possess this knowledge from their use of spoken language. The orthography-phonology mapping is easy to learn because the codes are highly correlated; the orthography-semantics pathway takes longer to become established because the mapping is more arbitrary. Over time, however, the orthography-semantics pathway begins to exert its influence, particularly for high-frequency words. Note, however, that what changes is the relative division of labor between the two pathways; there is some input from both pathways for almost all words.

In summary, the division-of-labor model explains why the phonological pathway predominates in early reading. However, it also contradicts the intuition that the orthography-semantics association is too arbitrary to play a useful role. Given the cooperation between the pathways, the orthography-semantics pathway only has to be good enough to clean up the pattern activated via phonology. When the model is trained to a high level of proficiency, both pathways contribute significantly.

Summary

Connectionist models have provided insights about many aspects of normal reading and reading impairments. The models have brought new ideas about learning and information processing into discussions of reading, lending support to some claims (e.g., about the role of phonology in reading ability and disability) while challenging others (e.g., that rule-governed forms and exceptions are processed by distinct subsystems). Although considerable progress has been made, the models raise many questions that need to be addressed in future research. The models do not address all aspects of reading; their implications concerning instruction and remediation have not been explored in depth; and it will be necessary to link the models more closely to the evidence concerning the brain bases of lexical processing that is emerging from neuroimaging (see the previous discussion in The View From Cognitive Neuroscience). The goal of developing an integrated account of reading behavior and its brain bases, with computational models providing the interface between the two, nonetheless seems a realistic one and is likely to be the focus of considerable research.

METHODS OF TEACHING READING

Much of the history of reading instruction in the United States has involved two general methods: whole-word instruction and phonics instruction. However, meaning-emphasis instruction, and especially whole-language instruction, has dominated the philosophy of training of reading teachers over the past 20 years. Originally, the time-honored *ABC* method was used to teach reading for about 200 years. This method was a basic type of phonics instruction in which children were taught letter names, then simple syllables, then words. The child would spell the syllable and then pronounce it: "double-you-ay-ell-ell—*wall*." Later, more syllables and words were mixed in, usually with the same spelling requirement prior to pronunciation. The *New England Primer*, *Webster's Spelling Books*, and *McGuffey's Readers* were the major sources of reading programs from the 1700s until the 1900s. Pictures were introduced into these programs, but for the most part the emphasis was on phonics drill. Although there is little evidence indicating how successful the ABC method was in teaching reading, there apparently was some dissatisfaction with it because educational reforms in the late 19th century led to the whole-word method becoming the predominant method of teaching reading. More recently, the whole-word method has been supplanted by whole-language instruction. In this section, we describe each method of instruction.

Whole-Word Instruction

To some extent, ideas about whole-word instruction are congruent in a general way with facts about spoken language. Spoken language is an almost continuous stream of sound with little or no silence separating the individual words, a fact that is especially noticeable when one tries to pick out word boundaries in a foreign language. However, compared with phonemes, words are more readily detected as units, and children come to recognize the spoken word as a meaningful unit. The relative invisibility of phonemes encouraged the view that whole words are the appropriate units for instruction. Typically in this kind of instruction, the child is shown a flash card with a word on it, and the teacher pronounces it and asks the child to say it. Generally, the teacher starts with a small set of words and gradually expands the set.

Another argument that has been used to support the whole-word approach is the low reliability of letter-to-phoneme mapping, a complex issue that we discussed in previous sections. The irregularity of English spellings, which occurs mainly in the vowel system, allows the word *pint* a different pronunciation than most words that end in *int*, which are pronounced as in *hint*. Similarly, *have* is irregular because most words that end in *ave* are pronounced as in *gave*. Irregular words such as *pint* and *have*, in any approach to teaching reading, must be learned at least partly in terms of their distinctive properties. The whole-word approach generalizes this approach to learning to read all or most words.

Advocates of the whole-word approach have also argued that it promotes reading for meaning at an early stage of reading. Words have meanings; speech sounds do not. When a child has developed a small sight vocabulary, this vocabulary is deployed in various combinations to construct meaningful sentences, and new words are introduced so that the context clarifies their meaning. The pronunciation is given by the teacher, who indicates, wherever possible, the similarity in spelling between the word to be read and a word already in the sight vocabulary. This makes it possible (after an initial sight vocabulary is established) to emphasize that the letter symbols represent sounds.

Phonics Instruction

Phonics instruction, in its purest form, starts with a limited set of correspondences between letters and speech sounds. These letters are used immediately to build many different kinds of words. In this way, phonics instruction takes advantage of the productive aspects of alphabetic writing systems. Gradually, more letters are added, and then consonant digraphs (*th*, *ch*) and eventually consonant clusters (*st*, *tr*) are introduced. As simple words are presented over and over, the child also naturally develops a sight vocabulary during these early stages, but the development of a sight vocabulary is largely incidental in phonics instruction (much as knowledge of the alphabetic principle is incidental in whole-word instruction). The individual letters are taught by the sounds they make, and then children are induced to blend the sounds of novel letter combinations.

The main rationale behind a phonics approach is that it explicitly teaches children both the alphabetic principle and the specific letter-phoneme correspondences that generalize across many English words. An additional benefit of phonics is that it promotes an analytic approach to words that can serve the child in encounters with unknown words. One criticism of phonics, repeated for more than 100 years (M.J. Adams, 1990), is that it is boring for the child. The reason for this criticism is the emphasis phonics places on letter-sound correspondences at the expense of reading for meaning. However, this complaint is more often about the practice of phonics lessons, which are often derided as "rote drill," than about the essence of the approach. The teaching of letter-phoneme correspondences is not the same as "phonic drills," as consumers of computer-based phonics programs can attest. Certainly, some forms of practice at producing phonemes and blending them together into a word may at times be boring for children (just as learning basic math facts may be boring). But learning to read new words independently can be very rewarding for children.

Meaning-Emphasis Instruction

In general, meaning-emphasis programs focus on language experiences of the child. Thus, the child dictates short stories and is taught to read the words he or she has dictated. Instruction in learning individual words usually emphasizes memorizing whole words, though some phonics drill may be incorporated into the program at later stages.

Within the class of meaning-emphasis programs are whole-language instruction and an earlier related approach, the *psycholinguistic* approach, based on the work of Goodman and Smith (Goodman, 1970, 1986; Smith, 1971, 1973; Smith & Goodman, 1971). Goodman suggested that reading is a "psycholinguistic guessing game" in which readers try to figure out the meaning of a text by using a variety of partly redundant *cuing systems*. There are three types of cues in this guessing game: semantic, syntactic, and graphophonic. The graphophonic cues represent general knowledge of spelling-sound relations; the syntactic cues represent knowledge of syntactic patterns and the markers that cue these patterns (such as function words and suffixes); and the semantic cues represent knowledge about word meanings and the topic. More recently, Goodman's ideas have been incorporated into the larger whole-language instruction movement. This type of instruction, like other meaning-emphasis approaches, relies heavily on the child's experience with language. Children are encouraged to guess words that are presented in the context of short stories, and the primary motivation of the method is to make reading fun for the child. Whole-language teaching typically includes frequent oral reading by the teacher and the use of authentic literature, rather than decodable text.

In an approach that otherwise avoids any specification of what should be taught, Goodman and Smith provided one clear suggestion: Phonics should not be taught. Furthermore, they argued that children should not be corrected when they make errors reading words. Neither the development of phonological awareness in general nor the development of specific knowledge about letter-sound correspondences is a priority in whole-language instruction. Whole-language advocates do not deny that phonological awareness and phonics knowledge are components of reading (though they are not considered as central to the process as the research findings indicate). But they do deny that the explicit teaching of phonics is necessary. Their basic argument is that explicit teaching of phonics does more harm than good to beginning readers because many of them find phonics somewhat difficult and boring.

Whole-language proponents suggest that the knowledge necessary for skilled reading—including phonics knowledge—can develop in the same natural way that spoken language develops. Weaver (1994), for example, in a book aimed at elementary-school teachers, wrote: "Just as they learn the patterns of oral language, so most children will unconsciously learn common phonics patterns, given ample opportunity to read environmental print and predictable and enjoyable materials, and ample opportunity to write with invented (constructive) spelling" (p. 197).

The various tenets of whole-language teaching are a set of interrelated ideas that suggest a coherent perspective. The logic is as follows: (a) Reading is a natural extension of language; (b) explicit teaching of phonics treats reading as a technical exercise rather than a natural extension of learning and thus has the potential to do harm by boring and frustrating the child; (c) explicit teaching of phonics is unnecessary for learning; (d) therefore, explicit teaching of phonics should be avoided; and (e) because phonics represents just one of several redundant cuing systems, if a child fails to learn some piece of phonics knowledge, other cuing systems will fill in the gaps when the child actually reads.

The problem with this method lies not in the logical connections among its tenets, but in the extent to which they are true. Goodman's suggestion that skilled reading is a psycholinguistics guessing game, for example, has largely been refuted by research on skilled reading, which demonstrates that skilled reading is not a guessing game and that phonological information is critically important in word identification. In fact, the three cuing systems are not equivalent in determining what word is actually read; the graphophonic mechanism plays a highly prominent role, particularly in reading acquisition. Furthermore, the view that learning to read, like learning to speak, is a natural act that the child teaches him- or herself how to do stands in marked contrast to the view more common among researchers—that learning to read is not a natural act (Gough & Hillinger, 1980; A. Liberman, 1999), and is very different from learning to speak, which is effortless and automatic for almost all children brought up in normal circumstances. No child needs a teacher to show him or her how to speak. It is sufficient to be a normally developing human being surrounded by other human beings speaking their language.

Learning to read presents an entirely different picture. All schools of thought agree that some amount of teaching is often (or even always) necessary. In particular, learning to read often requires some explicit instruction in the alphabetic principle. Contrast this with learning to speak. No child needs to be taught the phonemes of his or her language, but every child needs to be taught the symbols that make up his or her writing system. That is why there is an alphabet song, but not a phoneme song. Furthermore, though all human societies have language, many do not have reading and writing.

It should be clear that we have some fundamental disagreements with some of the claims made by whole-language advocates. However, to this point, we have presented only arguments regarding the possible efficacy of whole-language instruction. In a later section, we review research findings more directly. Here we do want to note some positive contributions of the whole-language movement (more recently called *literature-based* instruction). First, and foremost, whole-language advocates have focused attention on the need to ensure that children are enthusiastic about books and eager to learn to read. They may go too far in their reliance on enthusiasm and eagerness as components of the process of learning to read, but no one can doubt the importance of these components, and whole-language proponents have been largely responsible for the growing trend to make reading instruction more meaningful. Furthermore, they have replaced an emphasis on the teacher as an agent of instruction with an emphasis on the child as an agent of his or her own learning. Certainly, appreciating the mutual roles of learner and teacher is an important step in establishing effective reading instruction, even if learning to read is not natural and spontaneous.

WHAT HAPPENS IN CLASSROOMS DURING READING INSTRUCTION?

The way we have discussed different methods used to teach reading may have implied that the method adopted determines what actually goes on in the classroom. However, many good teachers are adaptive rather than rigid in their approach to teaching children and only loosely base their instruction on a given method. They know by instinct that when learning is made meaningful and exciting, children learn more. It should also be noted that most schools are populated by a couple of generations of teachers who were taught that whole-language instruction is good and phonics is evil. So teachers may be asked to teach phonics and not know how, which also affects what happens in classrooms.

These days there are a large number of commercially available reading programs in schools. Because these programs can be rather expensive and because bulk buying is generally cheaper than buying different programs for different schools, school districts often adopt a single program for districtwide use. These programs, called basal reading series, consist of teacher guides, student materials (e.g., minibooks, anthologies, and workbooks), and ancillary materials (e.g., letter cards, posters, and CDs). Although each reading program generally adheres to one particular method for teaching reading, within individual classrooms, teachers have some flexibility in what they actually do if they are trained in a variety of methods.

The key word currently used to describe classroom reading instruction is *balance*. Reading instruction that balances instruction in phonics with exposure to good literature and opportunities to write is found more and more in classrooms. However, what balanced reading instruction involves in practice varies with respect to the explicitness with which skills are taught, the kinds of materials used to practice these skills, the size of the instructional group, and the extent to which assessment informs instruction. Truly balanced instruction should integrate skills instruction with reading for meaning and opportunities to learn (Snow, Burns, & Griffin, 1998). However, what often happens in primary-grade classrooms is a fragmentation of the literacy curriculum into activities based on the latest teacher training workshop. More generally, variations in actual classroom practice roughly fall under two approaches to teaching that we call prescriptive (direct) versus responsive teaching.

Prescriptive Teaching

Reading instruction that explicitly or directly teaches skills such as letter-sound correspondences typically consists of a curriculum with a prescribed set of activities, which together are called a *scope and sequence*. Across kindergarten and first grade, the curriculum systematically introduces phonological awareness and phonic skills with practice in decodable texts (containing letter-sound correspondences taught by the teacher). Beyond second grade, there is still some phonics in spelling instruction but not in reading instruction.

Instruction based on prescriptive teaching may vary in the amount of whole-class versus small-group instruction and in the amount of assessment. For example, the Open Court (2000) basal reading series emphasizes whole-class instruction and additional independent practice, with little emphasis on assessment. In contrast, in *Reading Mastery* (Englemann & Bruner, 1995) reading instruction takes place in groups of six based on placement tests. The school-reform model Success for All (Slavin, Madden, Dolan, & Wasik, 1996) has multiple grouping formats—whole-class instruction according to reading level determined by 8-week assessments, partner reading, independent reading, and collaborative group work.

First-grade teachers adhering to prescriptive techniques tend to plan their lessons around the following activities: (a) review of letter sounds previously taught, (b) introduction of new letter sounds, (c) practice blending sounds into words, (d) practice reading in decodable texts, (e) teacher read-alouds from children's literature to teach vocabulary and comprehension strategies, and (f) language arts (spelling, writing, grammar, and mechanics). For example, in the Open Court reading program, the teacher introduces /e/ (which corresponds to the linguistic symbol /ɛ/) spelled *e* by hanging the sound-spelling card *hen* on the wall (along with the other sound-spelling cards already introduced). The capital and lowercase printing of the letter (*E e*) is at the top, the picture of the keyword—*hen*—appears below, and in a green field at the bottom is the printed letter *e* (see Fig. 10). The children have been taught that the green field denotes short vowel sounds.

At the start of the lesson, the teacher reads the decodable story *Jen's Hen*—"Jen's pet hen likes to peck, peck, peck. She pecks at a speck on the new red deck. This is how her pecking sounds: /e/ /e/ /e/ /e/ /e/." Then, the teacher asks the children to listen to words and to signal thumbs-up when they hear a word that has the /e/ sound at the beginning or at the middle of the word. So, the children give a thumbs-up to *ever*, *etch*, *every*, and *echo*, but not *hand* or *flavor*, for /e/ sounds at the beginning, and a thumbs-up for *hen*, *pest*, *wet*, *desk*, *next*, *bed*, and *feather*, but not for *tape* or *bike*, for /e/ sounds at the middle of the word. In the next step, the teacher has the children blend words (both in isolation and in sentences) that contain short *e*. A specific procedure is outlined for teaching blending. For example, to blend *fed*, the child is taught to isolate the initial sound (/f/) and the medial sound (/e/), then to combine them (/fe/) before adding the final sound (/d/) to produce the entire word (/fed/). Finally, the phonics lesson ends by practicing the accumulating letter sounds in *Jen's Pen* (see Fig. 11). Before reading the story, the teacher reviews the high-frequency words

Fig. 10. A first-grade teacher pointing to the sound-spelling card for /e/ in Open Court Reading (2000).

Fig. 11. Page 3 from the phonics minibook *Jen's Pen*. From *Collections for Young Scholars*, by Open Court Reading, 2000, Chicago: SRA/McGraw-Hill. Copyright 2000 by SRA/McGraw-Hill. Reprinted with permission.

would, *my*, *did*, *laugh*, *out*, *her*, *of*, and *move* and teaches two new nondecodable words, *darts* and *feeds*. The teacher notes that one word with a variant spelling for "short e" (i.e., __*ea*_ in *bread*) is included in the story. This emphasis on decoding instruction is complemented in the language arts section of the lesson by teaching children to encode the sound-spelling /e/ through dictation practice.

Responsive Teaching

In contrast to prescriptive teaching, responsive teaching is loosely based on the constructivist notion of *scaffolding* (see Foorman, Francis, Shaywitz, Shaywitz, & Fletcher, 1997, for further discussion). Rather than working from a scope and sequence, the responsive teacher responds to what the child is perceived to need at the moment in the context of reading real books. The teacher provides a scaffold against which the child can construct knowledge of reading. Like whole-language instruction, responsive teaching is steeped in the belief that children inherit three cuing systems (syntactic, semantic, and graphophonic knowledge) from their oral language abilities. For example, in the tutorial program *Reading Recovery* (Clay, 1993), the classroom teacher not only provides feedback on oral reading errors, but also responds to an error by extending the child's knowledge of the alphabetic system. Furthermore, the responsive teacher keeps a running record of reading miscues to inform the next day's alphabetic activities of making words and breaking words into constituent elements. Because instruction in alphabetic coding is conducted incidentally in the context of reading books, responsive teaching methods inherently lack a systematic approach to phonics instruction. The absence of sequential instruction and practice makes it difficult for many children to acquire and transfer decoding skills.

Responsive teaching can be highly effective when knowledgeable teachers work with individual children. But responsive teaching in the hands of a teacher who does not have the knowledge to seize the moment productively or who is teaching a large group of heterogeneous readers may be ineffective with the lower-achieving students. A popular system for responsive teaching at the classroom level is *Guided Reading* (Fountas & Pinnell, 1996). Guided reading starts with whole-class discussion of a reading selection to elicit prior knowledge and introduce difficult vocabulary. Then the teacher scaffolds children's reading of the passage in whole-group, small-group, or partner-reading formats. If a small-group format is adopted, children work in centers or independently while the teacher works with one reading group after the other.

The current basal reading series have accommodated guided reading by providing *leveled text* (i.e., texts that are ordered by difficulty, according to a number of factors such as number of words, predictability of syntactic patterns, word frequency, and picture clues). These texts stand in contrast to the decodable texts of the prescriptive approach because they are selected for their sense of story and predictable syntactic patterns, and words are selected for frequency, not for sound-spelling patterns. But the issue of what makes text decodable for which readers at which phase of reading development is a largely unanswered empirical question (Juel & Roper/Schneider, 1985; Pearson, 1999). An example of leveled text is shown in Figure 12. The pages in this figure are from the story *The Bus Ride* (Scott, Foresman and Company, 1976), which is appropriate for mid-fall of first grade. In contrast to *Jen's Pen* (Fig. 11), which shows tight control on vocabulary with an emphasis on the /e/ sound from the lesson and previously taught letter-sounds, *The Bus Ride* emphasizes the predictable pattern "got off/on the bus."

Because of the new emphasis on phonological awareness and phonics, guided reading now includes a separate emphasis on words (P.M. Cunningham, 1995; Fountas & Pinnell, 1998). This means that in addition to guided reading, independent reading, and process writing blocks of an integrated reading-language period, many primary-grade classrooms now include a block of time devoted to word-level activities. During this daily block, the teacher teaches children how to read and spell high-frequency words and discusses strategies for decoding and spelling. P.M. Cunningham (1999) developed a curriculum of activities for word work (e.g., organizing words on a wall

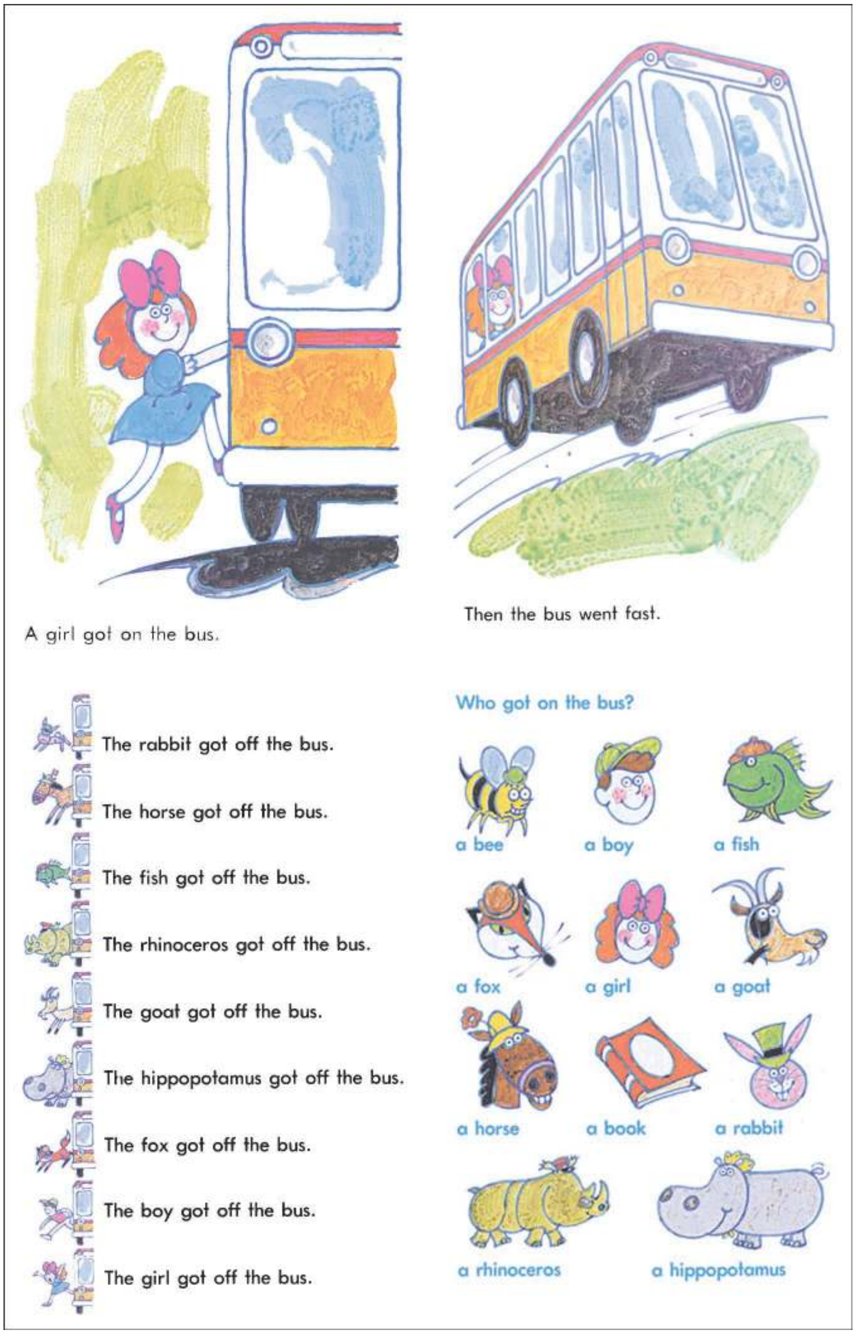

Fig. 12. Four pages from *The Bus Ride*. The top left panel is the second page of text in the book. The top right panel shows the third page. The book continues with a number of animals getting on the bus, followed by the page (p. 22 in the book) in the lower left panel, which emphasizes the predictable sequence "the [animal] got off the bus." The lower right panel (p. 24 in the book) shows the different animals in the story. From *The Bus Ride*, by Scott, Foresman and Company, 1976, Glenview, IL: Pearson Group. Copyright 1976 by Scott, Foresman and Company. Reprinted with permission.

chart according to letter-sound patterns, building words with magnetic letters, using words you know, guessing the missing word in a sentence). These activities all emphasize analogical reasoning around onsets and orthographic rimes, in contrast to the synthetic phonics approach taken by the majority of prescriptive teaching approaches. That is, a responsive teacher will have children sort printed words by initial sounds and then by word families (such as the *ould* in *could*). The danger is that these strategies can result in a look-at-first-letter-then-guess decoding strategy such as pronouncing *shot* as *ship* or categorizing only by rimes (*make*, *bake*, *rake*) rather than also by vowel spellings (*make*, *rain*, *play*, *eight*). Full mastery of the alphabetic system requires understanding how spellings represent speech sounds, and the inconsistency of this mapping for vowels provides a challenge for beginning readers of English (see Fig. 2). However, as we discuss in the section on research findings, there is an adequate empirical base to support phonics over nonphonics instruction, but not an adequate base to support one type of phonics instruction over another (e.g., synthetic vs. analogical).

Summary: Balanced Reading Instruction

In the first years of the new millennium, the language of balanced reading instruction has swept America's classrooms and basal textbook market. However, underlying the rhetoric lurks the reality of the debate over reading methods. Prescriptive teaching follows a scope and sequence of phonic elements, with texts based on the accumulating set of letter-sound correspondences taught. Responsive teaching eschews a scope and sequence in favor of strategies that enable the child to construct meaning in texts leveled by difficulty according to a number of factors (such as word frequency). Recently, responsive teachers have begun to attend more to word-level work that emphasizes an analogical approach to reading and spelling words and are often turning to phonics kits to supplement their letter-sound instruction. Unfortunately, the continued dichotomy of reading philosophies produces fragmented instruction in classrooms rather than the integrated balance of skills and meaningful applications that research suggests are needed to produce successful readers.

READING INSTRUCTION IS A POLITICALLY CHARGED ISSUE

During the 1990s, concerns about the effectiveness of reading instruction led to what are often called *reading wars* in a number of states where state officials became very involved in debates about reading instruction. In this section, we focus on Texas, California, and Massachusetts as examples of how politically charged the issue is. We also note that concerns among many parents have led to increased enrollments in many private schools. In general, this trend has occurred because many private schools have relied on phonics instruction, whereas many public school systems have used whole-language approaches to teaching reading.

Because of their large populations, Texas and California have had special status since the 1960s in decisions regarding the adoption of basal readers. The readers adopted by school districts in Texas and California often become the textbooks for the entire nation. Both states have grass-roots parents organizations and business coalitions that push educational agendas which affect national educational policy (such as California's Proposition 227 ending bilingual education in 1998). In Texas, the classic example of a politician involved in educational issues is Ex-Governor George W. Bush, who made education (and, in particular, reading) the focus of election campaigns, with a rallying call of "All children shall read at or above grade level by third grade!"

In the 1980s, the book *A Nation at Risk: The Imperative for Educational Reform* (National Commission on Excellence in Education, 1983) inspired a number of educational reforms. In Texas, the legislature passed reforms establishing minimum passing scores for courses and tests, minimum competency tests for teachers, and a "no pass—no play" rule that prohibited students who failed from participating in extracurricular activities. Legislation established an accountability system tied to students' performance on statewide tests and the development in the early 1990s of the Texas Assessment of Academic Skills (TAAS). Much has been written (see McNeil, 2000) about Texas's experience with the TAAS as the epitome of the negative consequences of high-stakes testing (e.g., bonuses to administrators and bribes to students led to test anxiety, cheating, and a TAAS-oriented curriculum). However, the public display of TAAS results school by school in local newspapers and across the state in the magazine *Texas Monthly* resulted in a groundswell of parent and business involvement in school reform at the local and state level. Much of this groundswell of parents was a cry of "We want more phonics!" directed at local school boards and the state school board. In fact, phonics advocates joined forces with social conservatives on the state board of education to try to mandate a phonics-oriented scope-and-sequence set of standards. Although this attempt failed, the social conservatives and phonics advocates were successful in passing a mandate that first-grade texts selected during the basal-reader adoption process be 80% decodable.

Texas also institutionalized its reading initiative at the local-district level. This was accomplished through several steps. First, a reading czar, who reported directly to the commissioner of education, was appointed at the Texas Education Agency, and this model was followed by several of the large school districts across the state. Second, the governor's office worked with the legislature to fund reading-related initiatives, such as early-reading assessments, early-reading interventions, and 4 days of professional development for the state's 40,000 kindergarten through second-grade teachers. Third, the state's curriculum standards were approved by a consensus committee, and textbooks that were subsequently adopted were aligned with the state standards. Fourth, coalitions of business leaders, university researchers, and professional educators used TAAS data and research findings to spearhead school reform in low-performing schools. At each step, districts are expected to make their own decisions about how state directives will be achieved. For example, districts can use "accelerated learning" funds for whatever early-reading intervention programs they want, but are held accountable for student outcomes. Additionally, districts choose from the commissioner's list of approved instruments which early-reading assessment will be administered.

In contrast to Texas's local-control approach to reading reform, California implemented a top-down approach that was a result of the state's plummeting scores on national assessment tests. From the early 1980s to 1994, California went from near the top to near the bottom in national comparisons. In 1995, the state superintendent of public schools put together a reading task force that prepared guidelines for reading reform. In that same year, the legislature passed the ABC Bill, which mandated explicit teaching of phonics, spelling, and math. This was followed by legislation providing money for staff development for teachers and administrators in effective early-reading techniques, including techniques for systematic, explicit instruction in phonics. In 1996, the California Department of Education released a program advisory on reading and language arts instruction, which was followed by the Reading/Language Arts Framework in 1999. Both documents were written by outside experts. While all of this was going on, California was also reducing class size, setting up an accountability system, calling for another textbook adoption, and eliminating bilingual education. With so much change occurring so fast, it is not surprising that California's reading-reform movement was severely criticized by university faculty and teachers (see Dressman, 1999; Mathes & Torgesen, 2000).

In Massachusetts, the situation was slightly different. Public education in Massachusetts has traditionally been much more decentralized than in Texas or California. There has typically been no statewide textbook adoption, and little history of state involvement in curriculum choice. These matters have been largely left up to local school systems. The 1993 passage of the Massachusetts Education Reform Act was thus a notable departure from tradition. Education reform promised major increases in state funding for public education. In exchange, local school systems were required to meet new state curricular standards, which were to be drawn up by committees appointed by the Massachusetts Department of Education and approved by the state Board of Education. The standards were to be enforced through a program of statewide testing.

Despite the traditional lack of centralized control, the curriculum in Massachusetts public schools looked rather uniform across the state. This is understandable: As everywhere, teachers and administrators took similar courses at the same handful of universities, attended the same workshops, and bought the same textbooks, responding to national trends and fashions. Consequently, reading instruction in Massachusetts was strongly influenced by the whole-language movement in the early 1990s. It is thus not surprising that the committee of educators charged with drawing up the curriculum framework on English language arts produced a document heavily influenced by the whole-language approach. The document that they produced contained no mention whatsoever of the scientific literature on reading, yet claimed support from research. It highlighted the idea that children could learn to read the same way they learned to talk—and presented a vision of language acquisition that attributed the process to curiosity and enthusiasm alone. Crucially, the document claimed support from research on language:

> In the past, research focused on the components of language—phonological and grammatical units. As a result, we understood and taught the language processes as separate entities characterized by discrete skills. More recently, language researchers have shifted their focus to study language from the perspective of its primary function—communication. (Massachusetts Department of Education, 1995, p. 14)

By analogy, the same shift was endorsed in reading instruction.

As it happens, Massachusetts is home to well-known centers of research in linguistics and the psychology of reading at the Massachusetts Institute of Technology and the University of Massachusetts at Amherst. Once the content of the proposed curriculum document became known to some of these researchers, a letter signed by 40 researchers in linguistics and psychology was sent to the Commissioner of Education on July 12, 1995. The letter objected to the document's claims about language and reading:

> We want to alert the educational authorities of Massachusetts to the fact that the view of language research presented in this document is inaccurate, and that the claimed consequences for reading instruction should therefore be subjected to serious re-examination.
>
> The facts are as follows. Language research continues to focus on the components of language, because this focus reflects the "modular" nature of language itself. Written language is a notation for the structures and units of one of these components. Sound methodology in reading instruction must begin with these realities. Anything else will shortchange those students whom these standards are supposed to help.
>
> We are concerned that the Commonwealth, through its powers to set standards for schools, should presume to legislate an erroneous view of how human language works, a view that runs counter to most of the major scientific results of more than 100 years of linguistics and psycholinguistics. We are even more concerned that uninformed thinking about language should lie at the heart of a "standards" document for Massachusetts schools.

By chance, the letter came along just as the reading wars were heating up in other states, and attracted considerable attention. Massachusetts responded quite positively, first revising its curriculum framework and finally rewriting it completely. The commonwealth's curriculum document (though controversial in other ways) has won praise for being a lucid and scientifically accurate description of the reading process that at least points to acceptable standards for early-reading instruction. In a sense, the Massachusetts story represents a victory for sound educational practice. Nonetheless, it is unclear how much has really changed for Massachusetts schoolchildren now that Massachusetts has a scientifically sound document underlying its standards for reading instruction. The most recent round of state testing continues to reveal harsh differences between rich and poor communities in reading achievement, and there is little sign that teachers are being educated about the research literature that underlies the commonwealth's current standards document.

Massachusetts, Texas, and California each reveal part of the way out of the reading wars. It is helpful when the research community is mobilized and gets itself involved, as happened in Massachusetts. But researchers do not make policy and do not teach young children to read. For true progress, there must be guidance from above, as in California, supporting and fostering strong local interest and enthusiasm from both parents and teachers, as in Texas.

Many obstacles stand in the way of this sort of progress. One is the peculiar alignment (particularly in North America) of phonics with conservative politics. Considerable publicity for the Massachusetts researchers' letter was generated by conservative newsletters and Web sites (a bit of an irony for a letter signed by 40 Massachusetts professors, including several well-known leftist activists). In like fashion, writings from the whole-language community proclaim that the essence of this approach lies not in its particular ideas about reading, but in its "belief in the empowerment of learners and teachers" and the "acceptance of all learners and the languages, cultures and experiences they bring to their education" (Whole Language Umbrella, 2000)—as if a pedagogy based on the alphabetic principle was inevitably inconsistent with empowerment and acceptance. In reality, of course, the pedagogy that empowers most is the pedagogy that teaches best.

RESEARCH FINDINGS ON TEACHING READING

We turn now to research findings related to how to best teach reading skills. We begin by reviewing two well-known summaries of research on teaching reading and then providing overviews of the findings of two recent reports on the issue: the National Reading Panel (NRP; 2000) report and a report of the National Research Council (NRC) called *Preventing Reading Difficulties in Young Children* (Snow et al., 1998). We then turn to a discussion of laboratory and classroom studies.

Meta-Analyses of Teaching Reading

The questions surrounding how reading is most effectively taught have been the object of several comprehensive reports over the years, including two major books (M.J. Adams, 1990; Chall, 1967). The question at the center of Chall's "Great Debate" review was, what does evidence have to say about the effectiveness of direct instruction—explicit phonics—compared with whole-word instruction or implicit phonics? Should beginning instruction focus on directly teaching the correspondences between letters and sounds (phonemes)? The logical answer to this question appears to be that these correspondences, and the alphabetic principle they instantiate, should be the central initial focus of instruction. However, the tendencies of actual practice have been otherwise. As noted earlier, a variety of alternative pedagogies have emphasized instead meaning-focused instruction built around story reading, exposure to print, and enhanced language environments. These alternatives are too varied to capture with a single characterization. For example, when Chall coined the term Great Debate in 1967, the alternative to direct instruction was whole-word teaching, in which basal readers and limited (and later) phonics instruction were typical components. In the past 20 years, the dominant alternative has been whole-language instruction. Chall's conclusion, based on a careful analysis of some 22 programs, classroom observations, and reviews of published studies, was that children who received direct code-based instruction (emphasis on decoding or phonics) tended to have higher achievement in the first three grades than did children in whole-word classrooms. Although initially, for beginning readers, whole-word classrooms performed better on measures of comprehension and reading rate, in later grades the advantage of decoding-based instruction became highly general, encompassing spelling, word recognition, and comprehension. This conclusion, in its general form, was confirmed in later less comprehensive reports.

M.J. Adams (1990) provided a thorough treatment of these research reports and, more generally, an evaluation of teaching methods in the context of research findings. Furthermore, she put the Great Debate in its historical context, and explained why there has been so much resistance to the direct teaching of decoding. An emphasis on meaning and comprehension not only coincides with the main goal of reading, but also appeals to beliefs that the child's experience in school should reflect purposeful learning in authentic contexts. In that spirit, the exclusive use of commercially published children's literature (which is often not decodable) has become characteristic of whole-language classrooms. Modern phonics advocates point out that there is nothing incompatible between these meaning values and good phonics instruction, which aims to quickly provide the child with the basics of the letter-sound system and practice with decodable texts while at the same time introducing children's literature. Like Chall, Adams argued that phonics approaches were more successful than nonphonics approaches in teaching children to read.

The NRC report

The NRC (the research arm of the National Academy of Sciences) revisited this issue in its report *Preventing Reading Difficulties in Young Children* (Snow et al., 1998). Unlike reports that have focused on the question of how to teach reading, the NRC report asked how available research findings can inform recommendations directed at reducing children's reading difficulties. A distinctive feature of the NRC report was that it considered early-childhood factors. It reviewed research on early childhood, including research on parental influences on cognitive and social development, family literacy, and the role of preschools as language and literacy environments. It also reviewed the problems of teacher preparation and made specific recommendations about what teachers need to know about reading. The report reviewed studies that reported low levels of teacher preparation in the foundations of reading. Adding to the growing call for stronger teaching preparation, the report recognized the need to improve both the college education (preservice training) and the in-service training of teachers.

Although the NRC report steered clear of specific curriculum recommendations, it emphasized the importance of promoting knowledge and practice in decoding. For example, it recommended that kindergarten instruction "be designed to provide practice with the sound structure of words, the recognition and production of letters, knowledge about print concepts, and familiarity with the basic purposes and mechanisms of reading and writing" (p. 322). It concluded that research shows that beginning reading "depends critically on mapping the letters and the spellings of words onto the sounds and speech units that they represent" (p. 321). Furthermore, counter to the idea that somehow comprehension can proceed on its own, the report added that "failure to master word recognition impedes text comprehension" (p. 321).

The report's focus on language and literacy experiences prior to school and on the importance of decoding knowledge as a goal of beginning reading instruction achieves a meaningful balance. It is clear that coming to school with certain relevant skills (some degree of phonological awareness) and dispositions (an interest in books) eases the burden of school instruction. It is equally clear that schooling can organize its efforts along the lines supported by research, making sure that children acquire the ability to decode words and have sufficient reading practice to gain fluency and increase comprehension.

The NRP report

In 1997, the U.S. Congress asked the National Institute for Child Health and Human Development and the Department of Education to convene a committee to examine applying reading research to classroom practice. Topics studied by the NRP were alphabetics (phonological awareness and phonics), fluency, comprehension, how teachers can be taught to teach reading better in certification and professional development programs, and the use of computer technology in reading instruction. Meta-analyses based on available data on these topics were undertaken.

The NRP (2000) study is valuable for what it found in the alphabetics area and what it did not find in the other areas (the committee decided that there was generally not enough good-quality research to make valid conclusions in some areas). The report noted the validity of the research we discussed previously in the section on phonological awareness. With respect to phonics instruction, meta-analyses revealed that (a) systematic phonics instruction produces significant benefits for students in kindergarten through sixth grade and for students with reading disabilities (regardless of SES), (b) the impact of phonics is strongest in kindergarten and first grade, and (c) phonics must be integrated with instruction in phonological awareness, fluency, and comprehension. The report noted that a strong empirical base supports the importance of instruction in phonological awareness, in conjunction with phonics instruction, for the beginning stages of reading instruction. However, the report also noted that there are not enough data to draw conclusions about the best way to teach vocabulary, fluency, and comprehension, or the best way to prepare teachers to teach reading.

Laboratory Studies

The results of some important experimental studies suggest two interrelated conclusions. First, learning correspondences between letters and sounds is more productive (so there is more transfer to new words) than learning whole words, even though learning whole words may be faster at first. Second, providing instruction that lets children infer these correspondences may not be as effective as directly teaching them. The first conclusion was demonstrated by C.H. Bishop (1964), who trained two groups of adult subjects to respond to novel visual stimuli. One group learned to make phoneme responses to individual Arabic letters, whereas the other group learned to make word responses to strings of Arabic letters. In each case there was a 1:1 correspondence between the graphic stimulus and the pronunciation. In the case of single letters, the correspondence was between the letter and the phoneme; in the case of the words, the correspondence was between the printed word and its pronunciation. Although training was faster for the whole-word group than the letter-phoneme group, transfer showed the opposite result: The letter-phoneme group could read many more new words than the whole-word group.

Jeffrey and Samuels (1967) carried out a similar study using kindergarten children and a set of specially constructed letters. They found that children who had learned the sounds of individual letters could correctly read many more new words than could children whose training required them to learn whole words. Although both groups learned the intended pronunciation of the new words, the word group needed twice as many trials as the letter group to reach this level of performance.

Thus, laboratory research has long established the value of learning letter-sound correspondences for productive transfer of reading skill. Other laboratory studies with children have shown how difficult acquiring these correspondences can be in the absence of instruction (Byrne, 1984, 1996). Byrne (1991) taught young children to read one-syllable words by pairing the words with their meanings; for example, *fat* was associated with a picture of a fat boy and *bat* was associated with a picture of a bat. Then, with the pictures withdrawn, the children demonstrated that they could read the words alone. One might think that the children had inferred that the *f* made the sound /f/, because the *f* was the only letter that distinguished *fat* from *bat* and the phoneme /f/ was the only sound that distinguished the spoken word "fat" from "bat." But instead, the children were unable to demonstrate that they had learned this association. When they were asked to judge whether the printed word *fun* said "fun" or "bun," their responses were incorrect about as often as they were correct. Thus, in at least some conditions, children do not spontaneously infer letter-sound correspondences on the basis of being able to read whole words. This finding reinforces the importance of teaching children directly what they need to learn.

Classroom Studies

Classroom studies of teaching reading typically have compared phonics instruction with some form of nonphonics (whole-word or whole-language) instruction. As noted, there have been many reviews of such research (M.J. Adams, 1990; Chall, 1967) in addition to the NRC (Snow et al., 1998) and NRP (2000) reports. All of these reviews (see also Chall, 1983, 1996; Feitelson, 1988) concluded that systematic phonics instruction produces somewhat higher reading achievement for beginning readers compared with the nonphonics alternative. Results are most impressive for students at risk for reading failure, such as children in Title I programs and those with learning difficulties.

If reviews are unanimous in their support for phonics, why does the debate continue? It continues because the debate is not just about whether the unit of instruction should be grapheme-phoneme mappings or whole words; rather, the debate is enmeshed in philosophical differences between traditional versus progressive education that divided American educators throughout the 20th century and continue to this day. The progressives, drawing upon the writings of Dewey (1938), champion student-centered learning over traditional education's emphasis on the uniformity of method and curriculum. The whole-language movement's emphasis on teacher empowerment, child-centered learning, and authentic literature is an outgrowth of progressive education. Likewise, its emphasis on constructivist psychology and on ethnographic and case study methodologies challenges the credibility of the empirical data-based approaches that dominate every field of scientific research (Foorman, 1995). Hence, conclusions based on classroom studies are contested on the basis of broad philosophical stances that are inconsistent with standard assumptions about research.

It is important to note that most of the whole-language movement's educational values are not necessarily inconsistent with teaching phonics. Indeed, schools of education could include a course in the alphabetic principle and phonics instruction for teachers in training. Then these teachers could enter first-grade classrooms empowered with the knowledge necessary to teach phonics without following scripted programs or relying on worksheets (Moats, 1994). In fact, few schools of education offer such a course.

First-grade studies

The U.S. Office of Education conducted the Cooperative Research Program in First Grade Reading Instruction between 1964 and 1967. These studies are commonly referred to as "the first-grade studies." Bond and Dykstra (1967) concluded from these studies that classroom approaches that emphasized (a) systematic phonics, (b) reading for meaning in vocabulary-controlled text, and (c) writing produced superior achievement compared with approaches that relied on mainstream basal readers that did not include phonics (only recently have systematic phonics instruction and decodable text been incorporated into mainstream basal reading series). They found a definite advantage for code-emphasis approaches but concluded that no single method worked for all teachers or all children. Phonics proponents emphasize the first part of the conclusion; whole-language proponents emphasize the latter part of the conclusion. Only recently have the multilevel modeling and statistical techniques become available to test for the separate and interactive effects of characteristics of students, teachers, and programs.

Evans and Carr (1985) evaluated two programs in 20 first-grade classrooms. Half of these were traditional teacher-directed classrooms in which instruction involved basal readers with phonics drills and applications. The other half were student-centered classrooms in which instruction by the teacher constituted only 35% of the day's activity. In the latter classrooms, reading was taught primarily by an individualized language-experience method in which students produced their own workbooks of stories and banks of words to be recognized (a whole-language approach). Evans and Carr characterized these two groups as *decoding oriented* and *language oriented*. Despite some differences in emphasis regarding how teaching should be conducted, the two groups did not differ in the amount of time spent on reading tasks. The two groups were also matched on relevant socioeconomic variables, and they were virtually identical on measures of intelligence and language maturity. The clear result, however, was that the decoding group scored higher on year-end reading achievement tests, including comprehension tests. Additionally, the language-oriented group did not show higher achievement in oral language measures based on a storytelling task. The results were consistent with the Pittsburgh Longitudinal study (Lesgold & Curtis, 1981; Lesgold & Resnick, 1982), which also showed quite clearly that instruction that emphasizes the alphabetic principle does not produce *word callers* who are insensitive to contextual meaning.

Effective-schools research

In the late 1970s and the 1980s, several syntheses of research on effective teaching were written (Brophy & Good, 1984; Rosenshine & Stevens, 1986). Effectiveness was defined in terms of correlations between classroom processes and student outcomes. The strongest correlates of achievement were instructional time engaged in academic tasks, classroom management, and certain patterns of teacher-student interactions (Soar, 1973; Stallings, Robbins, Presbrey, & Scott, 1986). For disadvantaged students, the link between explicit instruction and achievement was notable (Stallings et al., 1986), a finding supported in other classroom-observation research (Brophy & Evertson, 1978; Good & Grouws, 1975). Current reading research builds upon this research by employing longitudinal, multilevel designs that nest time within student, student within classroom, and classroom within school. By so doing, researchers are able to examine the impact of teachers and schools on the growth and outcomes of individual students over time. Thus, although the effective-schools research provides correlations between students' time-on-task and achievement outcomes, new methodologies in the 1990s made it possible to model how teachers' effectiveness mediates the impact of students' initial skill levels on skill development and achievement. And by modeling these effects within schools, researchers can begin to understand why students in some schools perform so much better than students in other schools.

Best practices

During the heyday of the whole-language movement (the mid-1980s to the end of the 1990s), educational researchers turned away from large-scale studies of classroom instruction and instead engaged in case studies of exemplary teachers and culturally different students. Case studies of culturally responsive instruction emphasized the small-group, collaborative approaches (Au, 1980; Philips, 1972) and the importance of relating classroom instruction to the home and community experiences of children (Delpit, 1995; Goldenberg & Gallimore, 1991; Heath, 1983).

In response to the assumption that best practices occurred in literature-based classrooms and not in skills-based classrooms, some recent research contrasted these two approaches (Morrow & Gambrell, 2000). The literature-based perspective is grounded in reader response theory (Rosenblatt, 1978), according to which readers play a central role in the construction of meaning, and in social-constructivist theory (Cullinan, 1987), according to which literacy is acquired in a book-rich context of purposeful communication. Literature-based instruction emphasizes sustained use of authentic literature for independent reading, read-alouds, and collaborative discussions. Skills-based programs, in contrast, are typically defined as traditional programs that use a commercially available basal reading program and follow a sequence of skills ordered according to their difficulty. Systematic phonics instruction falls under this definition of skills-based programs, whereas literature-based instruction is a more recent term for the whole-language approach. Literature-based instruction was found to benefit literacy acquisition in kindergarten (Castle, Riach, & Nicholson, 1994; Reutzel, Oda, & Moore, 1989) and at the elementary level (Freppon, 1991; Purcell-Gates, McIntyre, & Freppon, 1995; Reutzel & Cooter, 1990). In sum, studies of "best practices" provided ethnographic and case studies of a small number of exemplary teachers, in contrast to the effective-schools research, which examined process-product correlations in a large number of classrooms in schools of varying SES and achievement levels.

Recently, the combination of literature-based instruction with traditional basal reading instruction has been found to be more powerful than traditional instruction alone (Dahl, Scharer, Lawson, & Grogan, 1999; Morrow, 1992; Morrow, Pressley, Smith, & Smith, 1997). In fact, balanced reading instruction seems to be replacing literature-based reading instruction (Fitzgerald & Noblit, 2000; Pressley, 1998), as the pendulum of reading rhetoric swings away from whole-language approaches toward phonics.

Evidence-based practices

Rather than simply describing teaching strategies of teachers nominated by peers for their best practices (or correlating processes and products as in the effective-schools research), current research is drawing on longitudinal and multilevel designs to examine the impact of student-level and teacher-level variables on skill development and achievement.

While whole-language proponents were advocating the virtues of literature-based instruction and condemning phonics and skills-based instruction in the 1980s and 1990s, researchers continued to examine how children's reading development was affected by the interaction of their characteristics with instructional factors. These researchers (M.J. Adams, 1990; Ehri, 1998; Foorman, 1994; Harm & Seidenberg, 1999; Perfetti, 1992) addressed the complex mappings of phonology to orthography that are required when learning to read English; they also appreciated that phonics is an ad hoc system of 90 or so rules for teaching reading that provides only a beginning focus on grapheme-phoneme relations when, in fact, there are as many as 500 spelling-sound connections that must be learned (Gough et al., 1992). Because of the sheer number of these connections, self-teaching is hypothesized as the mechanism by which children continue their reading development beyond basic levels (Share, 1995; Share & Stanovich, 1995). Self-teaching assumes a foundation of phonological awareness and decoding skill upon which to bootstrap new orthographic information. Several researchers have investigated how this knowledge interacts with instruction in classroom settings. Juel and Roper/Schneider (1985) found that if the dominant instructional strategy in the classroom was decoding unknown words letter by letter, children learned the strategy quicker and went on to infer untaught letter-sound relations faster if their beginning reading textbooks contained decodable text. This was particularly true of children with low initial levels of skill.

Foorman, Francis, Novy, and Liberman (1991) found that students in three first-grade classrooms with more letter-sound instruction improved at a faster rate in reading and spelling than students in three first-grade classrooms with less letter-sound instruction. Initial scores on phonemic segmentation tasks predicted reading and spelling outcomes for all children. Exploratory data analysis revealed that children who were slow to improve in phonemic segmentation were also slow to spell and read phonetically, especially among children receiving less letter-sound instruction (Foorman & Francis, 1994).

In a subsequent study, Foorman et al. (1998) examined the reading development of 285 first and second graders in 66 classrooms in eight Title I schools to determine how the nature of letter-sound instruction interacted with entering skill in phonological awareness. These students scored in the bottom 18% on the district's early literacy assessment. Some teachers participated in one of three kinds of experimental classroom reading programs, and some participated in an unseen control group involving the district's standard curriculum. Instruction in all four groups included a language arts emphasis on writing and read-alouds from good-quality literature. The three types of experimental programs were differentiated by the kind of phonics instruction: (a) direct instruction in letter-sound correspondences practiced in decodable text (direct code), (b) less direct instruction in systematic sound-spelling patterns embedded in authentic literature (embedded code), and (c) implicit instruction in the alphabetic code while reading authentic text (implicit code). The 53 teachers for these three groups participated in ongoing generic staff development as well as training specific to their program. The remaining 13 teachers participated in the district's whole-language staff development, and their students formed a control group for the implicit-code approach.

Children receiving direct-code instruction improved in word reading at a faster rate and had higher word recognition skills than those receiving implicit-code instruction. The improvement was particularly impressive for students who began the year with low phonological awareness. Children receiving direct-code instruction, in contrast to children in the other groups, also had word-reading and reading comprehension skills that approximated national averages at the end of the year. Despite the direct-code group's generally good outcomes, 35% of them remained below the 30th percentile in reading achievement. Torgesen (2000) multiplied the percentage of students remaining below the 30th percentile (35% in this case) by the percentage of the distribution of reading scores represented by the students at the beginning of the year (18% in this case) to derive a population-based failure rate. Accordingly, Torgesen computed the population-based failure rate for the Foorman et al. (1998) study as 6% (35% × 18%). Fletcher and Lyon (1998) pointed out that a failure rate of 6% represents a substantial reduction in the 15% to 20% of students with reading difficulty in the United States. The finding that explicit instruction in letter-sounds can prevent reading difficulties for children at risk for reading failure because of poor phonological awareness or lack of home literacy has been demonstrated a number of times (Anderson, Hiebert, Scott, & Wilkinson, 1985; Foorman et al., 1998; Juel, 2000; Torgesen et al., 1999; Vellutino et al., 1996; Williams, 1980).

The other side of this apparent ability-by-treatment interaction is that first graders who enter with middle-range literacy skills benefit from classrooms with ample opportunities to read trade books (Juel, 2000). In an investigation of 4,872 kindergarten children in 114 classrooms where reading curricula (informed by ongoing professional development) varied in the degree of teacher choice and in the degree to which phonological awareness was incorporated, less teacher choice and more explicit incorporation of phonological awareness was associated with less variability across teachers in letter knowledge and phonological awareness at the end of kindergarten and in reading achievement at the end of first grade (Foorman et al., 2001). More teacher choice and a moderate number of phonological-awareness activities (mostly in the form of letter-sound instruction) were associated with more outliers—high-scoring children—at the end of kindergarten and first grade.

The effects of instruction can persist beyond the first grade, and they can be manifest in spelling as well as reading. Bruck, Treiman, Caravolos, Genesee, and Cassar (1998) compared spelling in third-grade children who had whole-language instruction throughout school and third graders who instead had received phonics instruction. The phonics-instructed children were better spellers, and their spelling of pseudowords included more conventional, phonologically accurate patterns.

In general, it appears that the clarity and organization of research-based components in the curriculum make a difference to reading outcomes. However, out-of-the-box implementations of basal reading programs are not likely to be effective. Again, ongoing professional development that provides the rationale for each component of reading (and spelling) instruction and provides classroom coaching to deal with the pacing of instruction, classroom management, and grouping of students is what helps teachers develop successful readers. Expecting teachers to put aside their basal readers and create their own curricula is not realistic given the lack of resources and of the knowledge base to do so (Moats, 1994).

Summary

Since the 1960s, classroom studies of reading methods have consistently shown better results for early phonics instruction compared with instruction emphasizing meaning at the level of words and sentences. This effect is particularly strong for children at risk for reading failure because of lack of home literacy or weak phonological-awareness skills (children who have attention problems, chronic ear infections, articulation problems, or a history of dyslexia in their families). This interaction between children's characteristics and curricular focus is moderated by instructional factors such as teachers' knowledge and competency. Thus, the kinds of materials (curriculum) and instructional strategies used interact with a child's stage of reading development in determining the child's success in learning to read. This fact has important policy implications for improving literacy levels nationwide. Yet in the national arena, reading methods have become highly politicized, and the Great Debate has turned into the reading wars. Proponents of literature-based instruction (Coles, 2000; B.M. Taylor, Anderson, Au, & Raphael, 2000; D. Taylor, 1998) have attacked research supporting skills-based instruction, despite the fact that this research investigates processes fundamental to learning to read rather than skills-based instruction per se. In return, skills-based researchers have pointed out how these attacks have misrepresented the research and are based primarily on philosophical objections (Foorman, Fletcher, Francis, & Schatschneider, 2000; Mathes & Torgesen, 2000). Despite the controversy, there is no question that continued scientific study of what constitutes effective reading instruction will benefit children and teachers by improving understanding of how particular children best learn to read.

SUMMARY AND CONCLUSIONS

In this monograph, we discussed a wide range of topics relevant to how children learn to read. We discussed evidence from developmental psychology concerning both the characteristics of children's language competency when they enter school and the nature of early reading development. We also discussed research on skilled reading (from cognitive psychology, cognitive neuroscience, and connectionist modeling) and the implications of this work for learning to read and teaching methods. Included in our discussion were arguments based on linguistic analyses, data from studies of skilled reading and brain activity during reading, and implications that follow from the implementation of connectionist models. Finally, we presented evidence from laboratory and classroom studies regarding the most effective methods for teaching reading.

From all these different perspectives, two inescapable conclusions emerge. The first is that mastering the alphabetic principle is essential to becoming proficient in the skill of reading, and the second is that instructional techniques (namely, phonics) that teach this principle directly are more effective than those that do not. This seems to be especially the case for children who are at risk in some way for having difficulty learning to read. It is also the case that the absence of instruction in phonics may increase the number of children at risk for becoming poor spellers (particularly because whole-language instruction often tolerates incorrect spellings). We do not deny the value inherent in various principles of whole-language teaching methods. As we noted many times throughout this monograph, instructional techniques that move beyond phonics practice to ensure the application of alphabetic principles to reading clearly support the process of learning to read. We also emphasized that the child's learning is every bit as important as the teacher's instruction. Obviously, using whole-language activities to supplement phonics instruction helps make reading fun and meaningful for children. Such activities may be most beneficial to children from environments where reading is not highly valued. But, at the end of the day, phonics instruction is critically important because it does help the beginning reader understand the alphabetic principle and apply it to reading and writing. Thus, the empirical data clearly indicate that elementary teachers who make the alphabetic principle explicit are most effective in helping their students become skilled, independent readers.

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