Lost in translation? Challenges in connecting reading science and educational practice

Mark S. Seidenberg[1], Matthew J. Cooper Borkenhagen[1], & Devin M. Kearns[2]

[1] University of Wisconsin-Madison

[2] The University of Connecticut

Author Note

To cite this work, use:

Seidenberg, M. S., Cooper Borkenhagen, M.J., & Kearns, D. M. (2020). Lost in translation? Challenges in connecting reading science and educational practice. Reading Research Quarterly, 55, S119-S130. DOI: 10.1002/rrq.341

This work was supported by the Vilas Trust, University of Wisconsin– Madison (Seidenberg and Cooper Borkenhagen); the Deinlein Language and Literacy Fund (Seidenberg); a grant (R305B150003) from the Institute of Education Sciences (Cooper Borkenhagen); and a grant 5P20HD 091013 from the National Institute of Child Health and Human Development (Kearns). The opinions expressed are those of the authors and do not represent views of the Institute of Education Sciences, the U.S. Department of Education, or the National Institute of Child Health and Human Development.

Correspondence concerning this article should be addressed to Mark S. Seidenberg, Department of Psychology, UW - Madison. E-mail: seidenberg@wisc.edu

Abstract

Can the science of reading contribute to improving educational practices, allowing more students to become skilled readers? Much has been learned about the behavioral and brain bases of reading, how students learn to read, and factors that contribute to low literacy. The potential to use research findings to improve literacy outcomes is substantial but remains largely unrealized. The lack of improvement in literacy levels, especially among students who face other challenges such as poverty, has led to new pressure to incorporate the science of reading in curricula, instructional practices, and teacher education. In the interest of promoting these efforts, the authors discuss three issues that could undermine them: the need for additional translational research linking reading science to classroom activities, the oversimplified way that the science is sometimes represented in the educational context, and the fact that theories of reading have become more complex and less intuitive as the field has progressed. Addressing these concerns may allow reading science to be used more effectively and achieve greater acceptance among educators.

Keywords: Reading science, educational practice, translational research

Lost in translation? Challenges in connecting reading science and educational practice

Reading is a remarkably complex activity involving most of our mental and neural capacities. As such it has been the focus of a massive amount of research by scientists from numerous disciplines who study human behavior and its brain bases. This interdisciplinary body of research constitutes what is sometimes called the science of reading (for reviews, see Castles, Rastle, & Nation, 2018; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001; Seidenberg, 2017; Snowling & Hulme, 2005). Many scientists who conduct this research have long believed that it could be used to improve educational practices and literacy outcomes (e.g., Adams, 1990; Stanovich & Stan ovich, 2003). That would be valuable, given persistently low literacy levels in the United States and other countries, especially among groups for whom factors such as poverty create many additional obstacles (Reardon, 2013; Snow, Burns, & Griffin, 1998). Previous efforts to connect this research and educational practice have failed for a variety of reasons (Seidenberg, 2017). The lack of improvement in literacy outcomes over many years has led to new pressure to incorporate the science of reading in curricula, instructional practices, and teacher education (Gewertz, 2020; Hurford, 2020). The pursuit of legislative remedies for low reading achievement in nearly every state (Davis Dyslexia Association International, 2020; National Conference of State Legislatures, 2019) is indicative of frustration over the lack of progress in addressing well-founded concerns.

These actions have revived long-standing disagreements about the causes of low literacy and how to address them. The arguments are distressingly familiar from the "Reading Wars" (for varied accounts, see Gunther & Lindstrom, 2003; J.S. Kim, 2008; Lemann, 1997). According to Seidenberg (2017), disagreements about reading education are a manifestation of a disconnection between the cultures of science and education, dating from the creation of U.S. schools of education in the early 20th century. Research on cognitive, linguistic, social, and emotional development that is highly relevant to education has been only fitfully incorporated in programs for teachers, curriculum developers, administrators, and policy experts. Educators working with scientists of an earlier era developed approaches to reading instruction based on assumptions that were falsified by extensive research, but these findings have had little impact on what teachers are taught, and widely used instructional materials continue to incorporate them (for discussion of one example, see Seidenberg, 2019).

The fact that the same conflicts have persisted under different names (skills vs. literacy, phonics vs. whole language, and phonics vs. balanced literacy) while literacy levels have been stagnant indicates that a different approach is needed. Concerns about reading instruction and teacher preparedness have been amplified via social media, advocacy groups, books (e.g., Goldstein, 2015; Seidenberg, 2017), and investigative journalism (Hanford, 2018), creating opportunity for change. Several states have initiated reforms centered on increasing teachers' familiarity with the science of reading, mandating the use of instructional practices that are consistent with it. Such efforts are gaining momentum (Gewertz, 2020; Goldstein, 2020).

Renewed interest in using reading research to improve practices is a welcome development. The potential benefits are substantial but remain largely untapped. The research base is extensive. Yet debates about connecting science and practice have hardly changed (compare articles in this special issue of Reading Research Quarterly with Stanovich & Stanovich, 2003, and J.S. Kim, 2008). Education is an enormous enterprise with numerous stakeholders whose interests often conflict: government, academia, business, voters, taxpayers, teachers, advocacy groups, families, students— and reading researchers. Change is exceedingly difficult to accomplish.

Many observers (e.g., Blaunstein & Lyon, 2006; Steiner & Rozen, 2004) have criticized the educational establishment, focusing on the schools of education that provide professional training for teachers and administrators and are the homes for experts in curriculum and instruction, policy, and other areas. The schools are not all alike: they contain numerous departments that represent different fields, and individuals' views certainly vary greatly. Reading science is conducted by some researchers in schools of education. Historically, however, they have deflected the influence of such science in teacher education, the development of curricula and practices, and educational philosophy, rationalizing why it lacks relevance and placing greater emphasis on a canon of accepted findings from earlier eras (Seidenberg, 2017). Scientific literacy—familiarity with core research findings; the ability to critically assess the quality of a research study, the validity of the conclusions, and their relation to other findings—is still not strongly emphasized in professional training, leaving practitioners susceptible to discredited or unsupported claims (e.g., the persistence of neuromyths; Dekker, Lee, Howard-Jones, & Jolles, 2012). Findings are cherry-picked from the vast literature to support personal beliefs and sell products.

Many educators have rejected the premise that their policies and practices are a major factor in poor reading achievement. Ravitch's (2011) argument that poor educational outcomes are due to external factors, principally poverty and government interference in her view, was enormously influential. It successfully deflected attention away from improving quality of education for the children for whom it matters most, it ignored the ways that educational practices magnify the impact of income inequality, and it wrongly implied that low literacy is limited to people in poverty (Seidenberg, 2017). Still, relative to poverty and government policy, using research to improve outcomes seems almost inconsequential. Similarly, the invention of "balanced literacy" successfully diffused the reading wars at their peak in the early 2000s without addressing the underlying issues. Declarations about the relevance of phonics by organizations historically opposed to it (e.g., International Literacy Association, 2019) could have a similar effect unless coupled with actions that change policies and practices. The pedagogical status quo is also sustained via a closed loop that includes educational authorities (academia), government (local, state, and federal officials who control budgets and policies), and educational publishing and technology corporations (producers of instructional materials). Many such authorities work closely with state departments of education and create products for the vast education market.

We do not wish to minimize the importance of these conditions, which create real obstacles that demand continued attention with the goal of achieving significant reforms. However, acknowledging other conditions affecting educational outcomes does not obviate the need to examine educational quality, which also has a strong impact, especially for students subject to other risk factors (Aikens & Barbarin, 2008). If the science of reading can improve students' learning and literacy, we need to use it, other factors notwithstanding.

Our goal in this article is to examine ways to make better use of science to improve outcomes, at a time when interest in the possibility is growing. We are concerned about uses of reading research that could undermine well-intentioned attempts to bring it to bear on pedagogy. The main products of this science are findings—systematic data about phenomena—and, more important, theories that are our best explanations for such findings. In reading, we have numerous theories because it is a complex behavior, the product of multiple skills and capacities; because reading is not a uniform activity but rather varies depending on purpose, skill, type of material, and context; and because it can be viewed from multiple intersecting perspectives (e.g., biological, behavioral, social, developmental, cross-cultural).

A theory of how students gain reading skills should (minimally) address what, how, when, and for whom. The what component is a characterization of the types of knowledge and mental operations (processes) relevant to tasks such as reading aloud and comprehending stories. The how part is a characterization of how the what is learned. The goal is a mechanistic account of how a learner gets from point A (e.g., the student cannot yet read) to point B (the student achieves escape velocity: basic skills that can develop further without much additional instruction about them). The when part refers to the fact that reading, like other acquired forms of expertise (e.g., gymnastics, mathematics), develops over an extended period of time. The nature of the skill demands that elements be introduced over time. So does the nature of the child: Capacities to learn change with development; what a child is able to learn also depends on the current state of their knowledge, which changes as they progress. For whom refers to individual differences among children that also determine answers to the other questions. For example, a child who is a native speaker of a different language or dialect than the one used in school has different needs than a child who already speaks it.

Every teacher acts on the basis of a tacit theory of what, how, when, and for whom, based on what they have been taught, learned from peers, and discovered from experience. The curricula they employ also instantiate assumptions in each of these areas. Incorporating reading science is valuable because it adds a vast amount to what is known about how reading works and how children learn, beyond what can be established by other means.

We have three concerns about current efforts to use this science to improve reading outcomes. First, there is a need for additional translational research to establish closer connections between theory and practice. We know more about the science of reading than about the science of teaching based on the science of reading. Second, we are concerned about how reading science has been characterized in educational contexts: It can be oversimplified in ways that slow progress by seeming to sanction practices that are only loosely connected to it. Finally, the science of reading is a moving target because it continues to progress. Theories have grown increasingly complex and nonintuitive, creating additional translational challenges.

We raise these concerns because the extensive body of research about reading may be used more effectively, and achieve greater acceptance, if they are addressed.

Lost in Translation?

Reading science does not come with educational prescriptions attached. Science is one kind of thing (empirical findings and explanatory theories), and educational practice is another (activities that promote learning in real-world settings). Connecting the two is the function of translational research. Given what is known about how reading works and students learn, what should be taught, when, and how? Which approaches are effective? For which students from which backgrounds and socioeconomic circumstances? Much has been learned from studies that used scientific theories and methods to investigate components of effective reading instruction (e.g., Vellutino, Tunmer, Jaccard, & Chen, 2007), devise effective interventions (e.g., McGinty, Breit-Smith, Fan, Justice, & Kaderavek, 2011; Morris et al., 2012), and identify factors that predict reading outcomes (e.g., Y.S. Kim, Petscher, Schatschneider, & Foorman, 2010). Our concern is that although reading science is highly relevant to learning in the classroom setting, it does not yet speak to what to teach, when, how, and for whom at a level that is useful for teachers.

To illustrate, consider research on the effectiveness of instruction that focuses on increasing students' knowledge of lexical phonology. Beginning readers who are progressing more rapidly exhibit better knowledge of the phonological properties of words, as measured by phonological awareness tasks such as deciding whether two words rhyme, indicating the number of syllables in words, and deciding whether two words end with the same sound or contain the same vowel (Castles et al., 2018). We know why: Reading depends on speech. Students do not relearn language when they learn to read; they learn to relate the printed code to existing knowledge of spoken language. Writing systems are codes for representing spoken language (Seidenberg, 2017). The structure of spoken words in English—the fact that they consist of sequences of phonemes, syllables, and morphemes that are associated with meaning—is reflected in their alphabetic representations. Learning about the written code is easier for students who know more about characteristics of spoken words that it represents. Individual differences in knowledge of such properties of spoken language at the start of formal instruction have an enormous impact on students' progress (Hulme, Nash, Gooch, Lervåg, & Snowling, 2015).

The translational question, however, is what to teach. For example, is it effective to focus instruction on building phonological awareness? Interventions of this sort have yielded very mixed results (Bus & van IJzendoorn, 1999). Sometimes improvement on the specific tasks that were the focus of instruction does not carry over to other tasks, such as reading comprehension (Blachman, 1997).

The picture changes if we consider the impact of such instruction in conjunction with other activities. Many studies have indicated that phonological awareness instruction is more effective when linked to instruction about print and meaning (e.g., Ball & Blachman, 1991; Bowyer-Crane et al., 2008; Byrne & Fielding-Barnsley, 1989; Cunningham, 1990; Gillon, 2000; Hatcher, Hulme, & Ellis, 1994; Schuele & Boudreau, 2008; Stuebing, Barth, Cirino, Francis, & Fletcher, 2008). Theories of reading can easily explain these results. The goal is gaining proficiency in reading (i.e., comprehending words and texts). Reading comprehension is facilitated by using print to access existing knowledge of spoken language. The development of phonological representations of words relevant to reading depends on one's experience with both spoken language and print. Thus, phonologically focused instruction is more effective when linked to knowledge of print in the service of reading for meaning.

That is good science, but what are the implications for instruction? Keeping in mind that the research in question concerns students, not preschoolers, the implications are something like these: Avoid teaching phonological awareness in isolation; emphasize connections among spelling, sound, and meaning; and link these activities to actual reading, the development of which is the instructional goal. Guidelines of this sort are useful. They might influence how teachers construe and pursue their instructional goals, but they do not speak to how to accomplish these goals. A teacher is more likely to seek that information from Pinterest and Teachers Pay Teachers (https://www.teacherspayteachers.com/). A lot of reading research has this character. The science is excellent; it is how we have learned so much about how reading works. Practitioners should know about it. Yet, there is a need to go the final translational mile to impact practice.

In short, one reason the science has not gotten into classrooms is because it has not provided sufficient guidance about what to do there. It is not only that cognitive science is not a part of teacher education. If it were clear to teachers how such science could improve their effectiveness and their students' progress, teachers would clamor for it. Some already do.

The imbalance between basic and translational research has created other problems. Consider phonics, for example. Phonics is not an important concept in theories of reading. Behavioral and brain evidence show that for skilled readers, orthography and phonology become deeply integrated (Seidenberg, 2017). For struggling readers, orthography and phonology are more weakly connected (Shankweiler et al., 2008). The obvious implication is that among other activities, early reading instruction should include ones that facilitate acquiring knowledge of the correspondences between print and sound—phonics.

Phonics is a translational issue. There has been research relevant to developing effective phonics instruction, demonstrating the advantage of direct instruction over indirect methods, for example (e.g., Foorman, Francis, Fletcher, Schatschneider, & Mehta, 1998; Stuebing et al., 2008). However, the research literature does not provide detailed guidance about which spelling–sound patterns to teach; how many to teach; whether patterns should be taught in isolation, such as all the pronunciations of the vowel o or in disambiguating contexts (e.g., words such as cot, cold, cost, doll, off); or other issues that have to be adjudicated for instruction to proceed. The market is filled with phonics curricula that fill the translational gap but vary greatly in assumptions about what to teach, when, and how, and thus are unlikely to be equally effective. Programs are motivated by science—students need to learn these mappings, which requires instruction, ergo phonics—but research has not validated specific solutions. Yet, that is what educators ask us: Which program does reading science say we should use?

In the absence of sufficient translational research, almost every reading curriculum can claim an equally loose connection to the "science of reading." The risk, of course, is that such programs will prove ineffective, not because the basic science is wrong but because the translation was poor. It has happened before. The unmet challenges involved in teaching phonics effectively, in the service of literacy while maintaining student motivation and interest, led influential educators (e.g., Clay, 2001; Goodman, 1989; Krashen, 2002; Smith, 1999) to conclude that beginning readers would be better off without it, which was a profound mistake. The educational challenges have no bearing on the validity of the science; being hard to teach does not change how reading works or what students need to learn. Worse, the alternative approach they developed—using contextual cues and strategies to guess words while discouraging the use of phonology by minimizing phonics instruction—makes it harder to learn to recognize words quickly and accurately, a basic ingredient of reading skill (Seidenberg, 2017).

It might be thought that the science-to-practice translation would be achieved via the educational publishing industry that produces curricula and other materials for teachers. Popular curricula (e.g., Reading Wonders: McGrawHill Education, 2014; Journeys: Houghton Mifflin Harcourt, 2014; Units of Study in Phonics: Calkins, 2019; Fountas & Pinnell Literacy Continuum: Fountas & Pinnell, 2016) were produced by teams of experts in education and science. Determining how science can be incorporated in such materials is presumably one of the tasks of such teams.

Commercial curricula do not accomplish this because they are compromised by the need to appeal to a broad market and to local authorities caught up in debates about best practices. The texts instantiate the balanced literacy idea that there is no single way to teach reading and that teachers should be free to use elements from different approaches. Rather than offering a best practices curriculum based on an effective translation of research to practice, teachers are left to construct their own. Their choices are likely to depend on their beliefs about reading and abilities to teach different kinds of material, not research-based recommendations about what to teach, how, when, and for whom.

The Science of Reading in the Educational Context

The science of reading that is the focus of legislation, inservice teacher training, and other educational reform is a simplified version of reading research. In these contexts, the science of reading concerns a relatively small number of key ideas and findings: the alphabetic principle (Liberman, Shankweiler, & Liberman, 1989), the simple view of reading (Gough & Tunmer, 1986), the four-part processor (Moats & Tolman, 2009), stages in reading development (Ehri, 2005), the five components of reading from the National Reading Panel (NRP) report (National Institute of Child Health and Human Development [NICHD], 2000), and a few others. Simplification is necessary to make research more accessible to teachers and other parties. It is a reasonable place to start, especially because the ideas are important yet still not universally known or accepted. However, reading science is an active, ongoing endeavor, not a canon of findings. Overreliance on simplified accounts of this research risks reifying it into precepts that do not incorporate much of what the science has to offer.

To illustrate, we turn to the NRP report (NICHD, 2000). As everyone knows, the report was "an evidence-based assessment of the scientific research literature on reading and its implications for reading instruction." The panel identified five components for which instruction had been shown to be effective: phonemic awareness, phonics, fluency, vocabulary, and comprehension. The report has been discussed ad nauseum. It was a valuable review that served several functions, including simply drawing attention to the existence of a body of science relevant to development and instruction. The reviews of evidence concerning phonemic awareness and phonics were significant at the time given how negatively they were viewed in the whole language approach. The report was also widely critiqued (see Allington, 2002; Shanahan, 2004).

For our purposes here, the main point is that the report was not a sufficient basis for designing an effective reading curriculum, but that is how it is frequently taken—today. The report mentioned but did not evaluate methods of instruction in each area. The panel did not evaluate existing curricula or describe the structure of an ideal curriculum based on their findings. That was not their charge. The report identified several targets for instruction supported by empirical research, but left open numerous questions about what to teach, when, how, and for whom, as the authors acknowledged.

Why are these observations relevant some 20 years after the report was published? Because in the context of the science of reading and education, it is often taken as having established the scientific basis for early instruction. The five components have been codified as the "five pillars of instruction" that reading curricula should incorporate (Cassidy, Valadez, & Garrett, 2010; J.S. Kim, 2008; McCardle & Chhabra, 2005). It does not detract from the historical importance of the report to note that it is not suitable for this purpose. Leaving aside the report's limited scope, the five components are not the same kinds of things. Phonemic awareness is a type of knowledge. Phonics is a type of instruction about correspondences between spelling and sound. Fluency is a characteristic of skilled reading. Vocabulary is a primary component of language, and comprehension—well, that is the goal. Whereas phonemic awareness is a very specific type of knowledge, vocabulary and comprehension are broad categories subsuming numerous types of information and mental operations, including ones that are not specific to reading (e.g., knowledge of what happens in a restaurant, making inferences about people's beliefs and intentions).

There is a further problem if these components of reading are treated independently, as in the NRP report (they were investigated by subgroups that wrote separate reports; NRP, 2000) and in curricula based on them. This is where the five-pillars approach seriously departs from reading research. The science addresses types of information and processes involved in reading and how they develop. What is missing from the list of components is a developmental account of how they are learned, information crucial for instruction. Researchers have studied these issues extensively. In fact, the components are highly interdependent. Phonemic awareness, the ability to treat words as consisting of discrete sound segments, is the outcome of a developmental process that begins with learning a spoken language and is finished by exposure to print (Bertelson & De Gelder, 1989). This process is affected by vocabulary size: Young learners begin discovering the internal structure of words via the overlap among them, which depends on the range of words they know (Metsala & Walley, 1998). Phonics, as it refers to learning spelling–sound correspondences, depends on not only phonemic awareness but also vocabulary, which allows learners to determine whether the way they pronounce a letter string matches a known word (Share, 1995). Vocabulary size and quality (Perfetti & Hart, 2002) affect comprehension, but comprehension is also a source of vocabulary learning (Landauer & Dumais, 1997). If these parts come together, learners gain fluency in identifying and understanding words and texts, and if they are fluent, learners can read more and learn more from what they read, about orthography, phonology, morphology, vocabulary, grammar, the connections among these types of knowledge, the ways that language is used to communicate, and the things we communicate about. In short, the components interact (Rumelhart, 1977). Skilled reading is possible because of the dependencies among these types of knowledge. Learning to read is possible because learning about one affects what is learned about others. Instruction based on these aspects of reading science would have a different character than practices based on separate components.

Our concern is not about the aged NRP report but about the way it is being used. It is not a good overview of the science of reading (too much omitted or out of date) but has been taken as such. It is not a sufficient basis for developing a curriculum but it has been taken as such. In extreme cases that we have observed, first grade reading instruction consists of blocks of time spent on each of the components, in the order they were presented in the report. The focus on the components leaves little time for reading and talking about books.

We have used the NRP report as our example, but the same questions can be raised about the use of other classic research. It is not that the ideas (e.g., the simple view of reading, the alphabetic principle) are wrong or unimportant; to the contrary, they are essential and need to be widely assimilated. Rather, they are incomplete, especially with regard to learning; they do not address individual differences adequately; and they do not include important ideas and findings that came later, many of which they stimulated. Together with insufficient translational research, overreliance on canonical studies leaves the door open to varied practices that reading science has not sanctioned.

The Science of Statistical Learning in Quasiregular Domains

We have discussed the need to bring reading science into closer contact with how learning occurs in educational settings. We observed that understanding what needs to be learned and how it is learned is a prerequisite for identifying effective practices and that the science of reading is an active endeavor, not a canon of findings. Our final concern centers on the challenges involved in making use of research that has become highly technical and theories that may not agree with intuition.

As sciences advance, the phenomena studied become increasingly remote from everyday experience. Instruments such as telescopes and microscopes have led to the discovery of phenomena (e.g., galaxies, molecules) that would not otherwise be known to exist. Advances in methods for analyzing data have revealed patterns that would not otherwise be detected. Despite reading's status as something we personally experience, such developments have occurred in reading science. Reading is mainly an internal event. The explanations for how we read refer to unobservable mental and neural operations. We study behaviors such as students' performance in matching words to pictures, reading sentences aloud with correct pronunciations and intonation, and answering questions about texts to draw inferences about these underlying events. However, the evidence now also includes data collected using specialized instruments (e.g., eye tracking, electroencephalography, neuroimaging), analyzed using advanced statistical and computational models that reveal latent factors, "hidden" knowledge, and levels of neural activity. These tools have taken our understanding of reading beyond the realm of intuition and direct observation. The question is whether discoveries based on such methods can inform instructional practices.

We can again illustrate using phonics. Skilled readers use their knowledge of the correspondences between print and sound to generate the phonological codes for words in silent reading. What is this knowledge and how is it acquired? Given the properties of written English, logic suggests that two types of information must be involved: rules to produce patterns such as save–pave–gave, which are also used in sounding out unfamiliar words (or, in research studies, pseudowords such as mave), and exception or sight words whose pronunciations violate the rules (e.g., have, said, bear) and must be memorized. For generations, dating back at least as far as the use of phonics methods in the early 19th century (Emans, 1968), this was the only account of how we manage to read words aloud. It is the core idea underlying the dual-route theory of reading (Coltheart, Davelaar, Jonasson, & Besner, 1977; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). The instructional implications of the theory are straightforward: Teach students the rules (or enough to allow them to "break the code"; Gough & Hillinger, 1980) and help them memorize the exceptions.

Although rules plus sight words remains the basis of phonics instruction, the approach is inadequate in several respects. What are the rules for pronouncing written English? No one knows. There are many ad hoc lists of rules varying in number and coverage, and there is little evidence that readers employ specific rules, such as those proposed by Coltheart et al. (2001) and Vousden, Ellefson, Solity, and Chater (2011). Beyond simple cases such as the pronunciation of vowels in consonant-vowel-consonant syllables, it is not clear what the rules are or even which words are rule governed. Is spook an exception because of book and look, or rule governed because of spoon and spool (Seidenberg, 2017)? Worse, it is unclear how students master the rules given that only a subset of them can be explicitly taught. Given these uncertainties, what should a teacher teach? The answer will depend on which phonics curriculum is being used or which instructional materials are downloaded from the internet.

Relating this theory to instruction raises a deeper question: What do students need to know to read aloud? The word know is ambiguous, of course. It cannot be that students need to know the rules of English pronunciation in the sense of being able to state them explicitly, because no one can. Moreover, the conscious application of rules is slow and effortful, the opposite of fluent. Perhaps readers use rules without being consciously aware of them. But how does a person learn a rule without awareness? There are several algorithms for deriving rules from language data (e.g., Albright & Hayes, 2003), but they are not realistic accounts of human rule induction. In phonics instruction, a subset of the rules is explicitly taught. How does explicit instruction turn into implicit knowledge, and how does instruction in a subset of rules enable learning of ones that are not taught?[1]

Given all of these concerns: one might ask, What if it is difficult to state the rules and how they are learned and decide on the sight words because the system is not rule governed? What if 200 years of phonics instruction has been based on a false dichotomy? This issue was moot until an alternative theory was developed by Seidenberg and McClelland (1989). Their work incorporated ideas about artificial neural networks, the type of computational learning system that in later, more advanced forms underlies the powerful form of artificial intelligence called deep learning. The framework, implemented in a series of computational models, has been described in detail elsewhere (e.g., Plaut, 2005; Seidenberg, 2005). Here, we can only briefly consider the what and how questions from before. The what question is about the knowledge and processes that underlie reading aloud. A neural network model learns to perform this task, taking a spelling pattern as input and producing its pronunciation as output (see Figure 1). The model represents knowledge of the correspondences between spelling and sound as a set of statistical dependencies (e.g., "ave" is usually pronounced as in "save" but differently in "have"). The network learns these dependencies based on experience (i.e., presentations of words and their pronunciations) using a statistical learning procedure based on how such learning occurs in the brain. The models are not taught a prespecified set of rules or mappings but rather discover them through learning to perform the task.

[1] The same ambiguity arises about awareness, as in phonological, phonemic, or morphological awareness. The term awareness is unfortunate. Teachers need to be aware of what phonemes and morphemes are, in the sense of being able to describe and identify them accurately, which can then inform their instruction. Readers do not need to know these things, however; they merely have to use them, rapidly and unconsciously. People managed to learn to read for thousands of years before linguists developed the concept of phoneme.

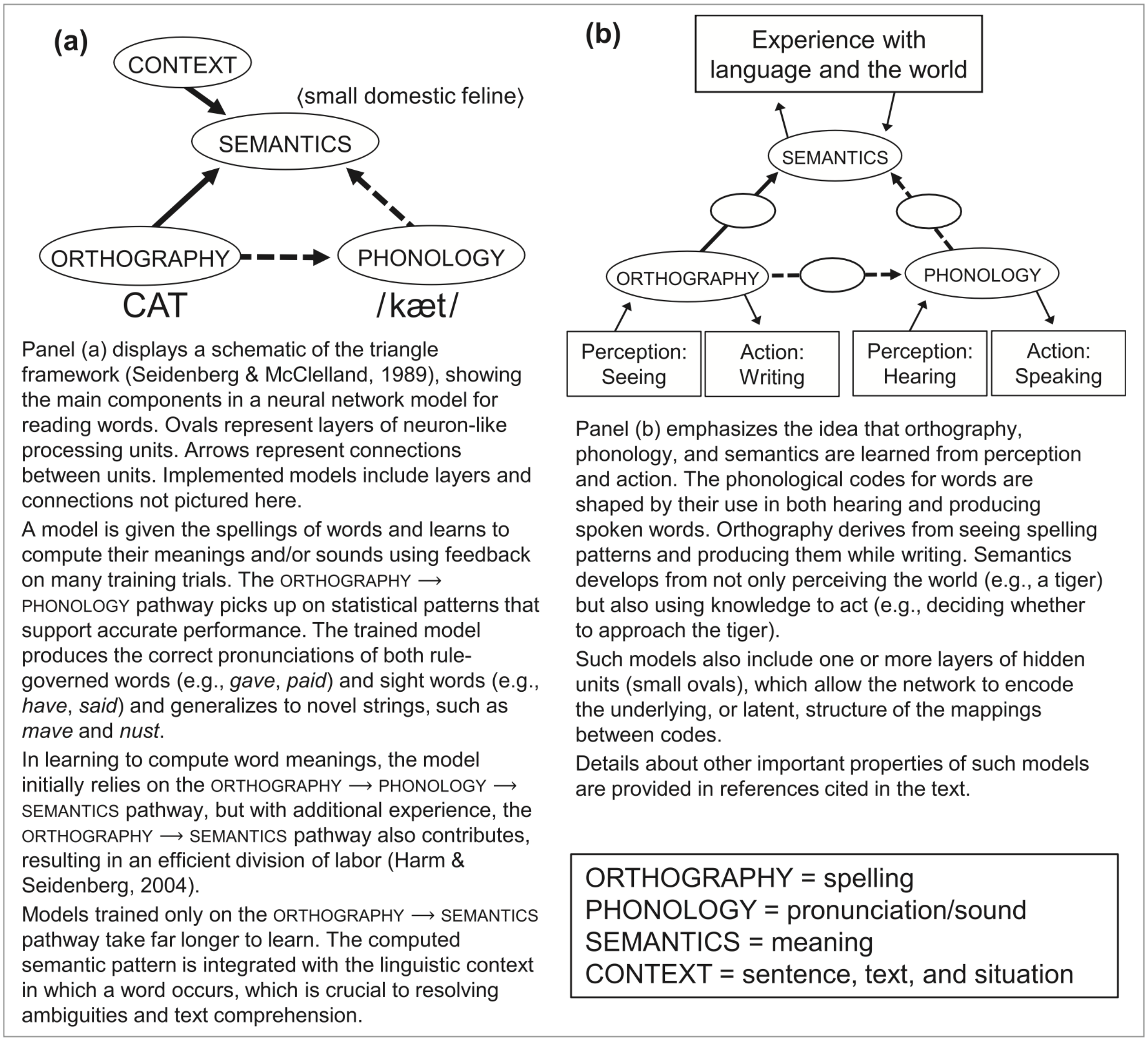

Figure 1. The Triangle Framework and Its Bases in Perception and Action

In this approach, words fall on a continuum of spelling– sound consistency, ranging from the most predictable, rule-like patterns to ones such as colonel and diarrhea, which are pretty terrible. There is no distinction between rule-governed forms and exceptions because they share structure: Putative exceptions such as have, said, and glove overlap with other words such as had, send, and globe, respectively. In a neural network, what is learned about a word carries over to other, overlapping words. Knowledge of have affects performance on rule-governed words such as save and gave and generalization to novel forms such as mave, evidence that they are learned, represented, and processed within a common system. Knowledge that is rule-like but also admits patterns that deviate in varying degrees is termed quasiregular (Seidenberg & McClelland, 1989). Quasiregularity is characteristic of language at many levels, including syllables, morphology, words, and grammar (Bybee & McClelland, 2005; Seidenberg & Plaut, 2014).

Models developed within this framework account for many empirical phenomena related to spelling–sound correspondences, including facts about learning, the development of fluency, and characteristics of performance at different skill levels. Such models have also been applied to related phenomena, such as the computation of word meanings from print or speech, and guided research on the brain systems underlying reading (Compton et al., 2019; Graves et al., 2014; Ueno, Saito, Rogers, & Ralph, 2011). This theory is not as intuitive as rules and sight words. It is hard to explain and hard for researchers to analyze how such systems work. Exploring this approach requires considerable background knowledge. The models are also incomplete in many respects. Yet, if they are a more accurate account of fundamental characteristics of reading, they should be relevant to instruction, bringing us to the how question.

Humans engage in at least two types of learning: explicit and implicit, also known as declarative and procedural (Ellis, 2005). The explicit system is associated with conscious awareness and intention, and procedures that can be described using language, such as the rules for chess. It is slow and effortful (cf. Kahneman's System 2 thinking, a related notion; Kahneman, 2011). The implicit system operates without conscious awareness, occurs automatically rather than by intent, and involves unlabeled statistical patterns (cf. System 1 thinking; Kahneman, 2011). The two systems work together, but their relative prominence depends on what is to be learned at what point in development. Consider, for example, the contrast between how children learn the grammar of a first, spoken language and how older people, such as college students, learn the grammar of a second language. A first language is learned via observation of and experience in using language to communicate. Children are not explicitly taught the rules of grammar; they pick up the structure of the language via statistical learning. Children have little awareness of the patterns themselves but learn to use them appropriately. We eventually gain awareness of some patterns by studying them, but that is to refine the language we have already learned (e.g., to conform to academic expectations).

Learning a second language in school is different. Rules of grammar are usually explicitly taught. Learning depends heavily on already knowing a language (e.g., to translate from one language to another) and requires intention and considerable effort.

With extended study, successful second language learners eventually begin encoding language statistics through usage. The first and second language examples illustrate that both types of learning are involved in both cases, but the balance between them shifts: implicit statistical learning more prominent in L1 and explicit rule learning and instruction in L2. The characteristics of firstand second language learning differ, as do the capacities of learners at different ages (Seidenberg & Zevin, 2006).

The question then is, what kind of task is learning to read words? The models developed by Seidenberg and McClelland (1989), Plaut, McClelland, Seidenberg, and Patterson (1996), Harm and Seidenberg (1999, 2004), and in related work suggest that it mainly involves implicit learning of the statistical structure of mappings between form (orthography and phonology) and meaning. This learning occurs in the background as children engage in silent reading or reading aloud or participate in other activities that provide opportunities to update this knowledge. The networks that support reading and language are updated every time we use them.

We also know, however, that some explicit instruction is necessary. Unlike very young children learning to talk, children do not begin to read until we teach them about reading, modeling it for them. Many aspects of written language are arbitrary, such as letter names and associated sounds. Children also must learn that print represents some aspects of spoken words (e.g., phonemic structure) but not many others that affect comprehension (e.g., voice quality, syllabic stress). Some studies have suggested that explicit instruction about a relatively small number of spelling–sound patterns can facilitate learning other, partially overlapping patterns (e.g., Steacy, Elleman, Lovett, & Compton, 2016). Explicit instruction can be seen as enabling statistical learning, and timely, targeted instruction can further accelerate it (for a related view, see Compton, Miller, Elleman, & Steacy, 2014). We do not yet know the optimal balance between the two systems for different learners, but learning phonics is more like learning a first language than learning a second one.

This framework has not been fully specified; much research remains to be conducted on the balance between the two learning systems and how to translate those findings into effective practices. The framework already provides a useful perspective on the long-running debate about phonics, which arose from different assumptions about the types of learning involved. At one extreme, children could be assumed to learn the correspondences on their own in a literacy-rich environment, an extreme implicit learning stance. This is not correct because it ignores the role of explicit instruction in jump starting the statistical learning component and accelerating it along the way to expertise.

At the other extreme, phonics programs often assume that these correspondences need to be exhaustively taught, like the rules of an exceedingly complex version of chess in which the allowable movements of the pieces are probabilistic and contingent on the surrounding pieces. Readers do not pronounce words by explicitly applying rules; doing so would be a conscious, slow, effortful process, the opposite of fluent. Teaching phonics by teaching rules and memorizing exceptions leaves out the statistical patterns that permeate the system and drive the implicit learning process.

We argue that neither extreme is correct. The goal is not balanced literacy but balanced learning: providing experiences that engage the implicit and explicit learning mechanisms to facilitate acquiring the statistical structure in quasiregular domains such as spelling–sound correspondences. This balance is not well understood but could be the focus of translational research. We have argued that instruction needs to cover what is necessary for children to learn, not merely what is familiar or easy. The same can be said of using the science of reading to inform instruction: We cannot merely focus on what is familiar or easier to digest.

Conclusion

We began by noting that the potential for using reading research (the science of reading) to improve literacy outcomes is substantial but has been largely untapped, and welcomed the renewed interest in making this connection. We identified three challenges to connecting science and practice (there are others; see Table 1). These challenges are serious but can also be addressed. Doing so is likely to increase the utility of the science in the classroom and its acceptance as a source of insight about instruction, benefiting teachers and students.

References

Adams, M.J. (1990). Beginning to read: Learning and thinking about print. Cambridge, MA: MIT Press.

Aikens, N.L., & Barbarin, O. (2008). Socioeconomic differences in reading trajectories: The contribution of family, neighborhood, and school contexts. Journal of Educational Psychology, 100(2), 235–251. https://doi.org/10.1037/0022-0663.100.2.235

Albright, A., & Hayes, B. (2003). Rules vs. analogy in English past tenses: A computational/experimental study. Cognition, 90(2), 119– 161. https://doi.org/10.1016/S0010-0277(03)00146-X

Allington, R.L. (2002). Big Brother and the national reading curriculum: How ideology trumped evidence. Portsmouth, NH: Heinemann.

Ball, E.W., & Blachman, B.A. (1991). Does phoneme awareness training in kindergarten make a difference in early word recognition and developmental spelling? Reading Research Quarterly, 26(1), 49–66. https://doi.org/10.1598/RRQ.26.1.3

Bertelson, P., & De Gelder, B. (1989). Learning about reading from illiterates. In A.M. Galaburda (Ed.), From reading to neurons (pp. 1–23). Cambridge, MA: MIT Press.

Blachman, B. (1997). Early intervention and phonological awareness: A cautionary tale. In B. Blachman (Ed.), Foundations of reading acquisition and dyslexia (pp. 409–430). Hillsdale, NJ: Erlbaum.

Blaunstein, P., & Lyon, R. (2006). Why kids can't read: Challenging the status quo in education. Lanham, MD: Rowman & Littlefield.

Bowyer-Crane, C., Snowling, M.J., Duff, F.J., Fieldsend, E., Carroll, J.M., Miles, J., ... Hulme, C. (2008). Improving early language and literacy skills: Differential effects of an oral language versus a phonology with reading intervention. Journal of Child Psychology and Psychiatry, 49(4), 422–432. DOI: 10.1111/j.1469-7610.2007.01849.x

Bus, A.G., & van IJzendoorn, M.H. (1999). Phonological awareness and early reading: A meta-analysis of experimental training studies. Journal of Educational Psychology, 91(3), 403–414. https://doi.org/10.1037/0022-0663.91.3.403

Bybee, J., & McClelland, J.L. (2005). Alternatives to the combinatorial paradigm of linguistic theory based on domain general principles of human cognition. Linguistic Review, 22(2–4), 381–410. https://doi.org10.1515/tlir.2005.22.2-4.381

Byrne, B., & Fielding-Barnsley, R. (1989). Phonemic awareness and letter knowledge in the child's acquisition of the alphabetic principle. Journal of Educational Psychology, 81(3), 313–321. https://doi.org10.1037/0022-0663.81.3.313

Calkins, L. (with colleagues from the Teachers College Reading and Writing Project). (2019). Units of Study in Phonics. Portsmouth, NH: Heinemann.

Cassidy, J., Valadez, C.M., & Garrett, S.D. (2010). Literacy trends and issues: A look at the five pillars and the cement that supports them. The Reading Teacher, 63(8), 644–655. https://doi.org/10.1598/RT.63.8.3

Castles, A., Rastle, K., & Nation, K. (2018). Ending the reading wars: Reading acquisition from novice to expert. Psychological Science in the Public Interest, 19(1), 5–51. https://doi.org/10.1177/1529100618 772271

Clay, M.M. (2001). Change over time in children's literacy development. Portsmouth, NH: Heinemann.

Coltheart, M., Davelaar, E., Jonasson, J., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), Attention and performance VI (pp. 535–555). Hillsdale, NJ: Erlbaum.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. Psychological Review, 108(1), 204–256. https://doi.org10.1037/0033-295X.108.1.204

Compton, D.L., Miller, A.C., Elleman, A.M., & Steacy, L.M. (2014). Have we forsaken reading theory in the name of "quick fix" interventions for children with reading disability? Scientific Studies of Reading, 18(1), 55–73. https://doi.org/10.1080/10888438.2013. 836200

Compton, D.L., Steacy, L.M., Petscher, Y., Rueckl, J.G., Landi, N., & Pugh, K.R. (2019). Linking behavioral and computational approaches to better understand variant vowel pronunciations in developing readers. New Directions for Child and Adolescent Development, 2019(165), 55–71. https://doi.org/10.1002/cad.20294

Cunningham, A. (1990). Explicit versus implicit instruction in phonemic awareness. Journal of Experimental Child Psychology, 50(3), 429–444. https://doi.org/10.1016/0022-0965(90)90079-N

Davis Dyslexia Association International. (2020, May 22). State dyslexia laws. Retrieved from https://www.dyslegia.com/state-dyslexia-laws/

Dekker, S., Lee, N.C., Howard-Jones, P., & Jolles, J. (2012). Neuromyths in education: Prevalence and predictors of misconceptions among teachers. Frontiers in Psychology, 3. https://doi.org/10.3389/fpsyg. 2012.00429

Ehri, L.C. (2005). Development of sight word reading: Phases and findings. In M.J. Snowling & C. Hulme (Eds.), The science of reading: A handbook (pp. 135–154). London, UK: Blackwell.

Ellis, N.C. (2005). At the interface: Dynamic interactions of explicit and implicit language knowledge. Studies in Second Language Acquisition, 27(2), 305–352. https://doi.org/10.1017/S027226310 505014X

Emans, R. (1968). History of phonics. Elementary English, 45(5), 602–608.

Foorman, B.R., Francis, D.J., Fletcher, J.M., Schatschneider, C., & Mehta, P. (1998). The role of instruction in learning to read: Preventing reading failure in at-risk children. Journal of Educational Psychology, 90(1), 37–55. DOI: 10.1037/0022-0663.90.1.37

Fountas, I.C., & Pinnell, G.S. (2016). The Fountas & Pinnell Literacy Continuum: A tool for assessment, planning, and teaching. Portsmouth, NH: Heinemann.

Gewertz, C. (2020, February 20). States to schools: Teach reading the right way. Education Week. Retrieved from https://www.edweek.org/ew/articles/2020/02/20/states-to-schools-teach-reading-the-right.html

Gillon, G.T. (2000). The efficacy of phonological awareness intervention for children with spoken language impairment. Language, Speech, and Hearing Services in Schools, 31(2), 126–141. https://doi.org/10.1044/0161-1461.3102.126

Goldstein, D. (2015). The teacher wars: A history of America's most embattled profession. New York, NY: Anchor.

Goldstein, D. (2020, February 15). An old and contested solution to boost reading scores: Phonics. The New York Times. Retrieved from https://www.nytimes.com/2020/02/15/us/reading-phonics.html

Goodman, K.S. (1989). Whole-language research: Foundations and development. The Elementary School Journal, 90(2), 207–221. https://doi.org/10.1086/461613

Gough, P.B., & Hillinger, M.L. (1980). Learning to read: An unnatural act. Bulletin of the Orton Society, 30, 179–196. https://doi.org/10.1007/BF02653717

Gough, P.B., & Tunmer, W.E. (1986). Decoding, reading, and reading disability. Remedial and Special Education, 7(1), 6–10. https://doi.org/10.1177/074193258600700104

Graves, W.W., Binder, J.R., Desai, R.H., Humphries, C., Stengel, B.C., & Seidenberg, M.S. (2014). Anatomy is strategy: Skilled reading differences associated with structural connectivity differences in the reading network. Brain and Language, 133, 1–13. https://doi.org/10.1016/j.bandl.2014.03.005

Gunther, N., & Lindstrom, C. (Producers). (2003). A tale of two schools: The documentary [DVD]. Available from http://www.pbs.org/weta/twoschools/documentary/

Hanford, E. (2018, September 10). Hard words: Why aren't kids being taught to read? APM Reports. Retrieved from https://www.apmreports.org/episode/2018/09/10/hard-words-why-american-kids-arent-being-taught-to-read

Harm, M.W., & Seidenberg, M.S. (1999). Phonology, reading acquisition, and dyslexia: Insights from connectionist models. Psychological Review, 106(3), 491–528. https://doi.org/10.1037/0033-295X.106.3.491

Harm, M.W., & Seidenberg, M.S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. Psychological Review, 111(3), 662–720. https://doi.org/10.1037/0033-295X.111.3.662

Hatcher, P.J., Hulme, C., & Ellis, A.W. (1994). Ameliorating early reading failure by integrating the teaching of reading and phonological skills: The phonological linkage hypothesis. Child Development, 65(1), 41–57. https://doi.org/10.2307/1131364

Hoff, E. (2013). Interpreting the early language trajectories of children from low-SES and language minority homes: Implications for closing achievement gaps. Developmental Psychology, 49(1), 4–14. https://doi.org/10.1037/a0027238

Houghton Mifflin Harcourt. (2014). Journeys: Common Core. Orlando, FL: Author.

Hulme, C., Nash, H.M., Gooch, D., Lervåg, A., & Snowling, M.J. (2015). The foundations of literacy development in children at familial risk of dyslexia. Psychological Science, 26(12), 1877–1886. https://doi.org/10.1177/0956797615603702

Hurford, D.P. (2020). The science of reading (a response to the New York Times). IDA Examiner, 9(1). Retrieved from https://dyslexiaida.org/the-science-of-reading-a-response-to-the-new-york-times/

International Literacy Association. (2019). Meeting the challenges of early literacy phonics instruction [Literacy leadership brief]. Newark, DE: Author. Retrieved from https://www.literacyworldwide.org/docs/default-source/where-we-stand/ila-meeting-challenges-earlyliteracy-phonics-instruction.pdf

Kahneman, D. (2011). Thinking, fast and slow. New York, NY: Macmillan.

Kearns, D.M. (2020). Does English have useful syllable division patterns? Reading Research Quarterly, 55(Suppl. 1).

Kim, J.S. (2008). Research and the reading wars. In F.M. Hess (Ed.), When research matters: How scholarship influences education policy (pp. 89–111). Cambridge, MA: Harvard Education Press.

Kim, Y.S., Petscher, Y., Schatschneider, C., & Foorman, B. (2010). Does growth rate in oral reading fluency matter in predicting reading comprehension achievement? Journal of Educational Psychology, 102(3), 652–667. https://doi.org/10.1037/a0019643

Krashen, S. (2002). Defending whole language: The limits of phonics instruction and the efficacy of whole language instruction. Reading Improvement, 39(1), 32–42.

Landauer, T.K., & Dumais, S.T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. Psychological Review, 104(2), 211–240. https://doi.org/10.1037/0033-295X.104.2.211

Lemann, N. (1997, November). The reading wars. The Atlantic. Retrieved from https://www.theatlantic.com/magazine/archive/1997/11/the-reading-wars/376990/

Liberman, I.Y., Shankweiler, D., & Liberman, A.M. (1989). The alphabetic principle and learning to read. Ann Arbor: University of Michigan Press.

Loeb, S., & Bassok, D. (2008). Early childhood and the achievement gap. In H.F. Ladd & E.B. Fiske (Eds.), Handbook of research in education finance and policy (pp. 517–534). New York, NY: Routledge.

McCardle, P., & Chhabra, V. (2005). Motivation and commitment in the interest of science and our children. Phi Delta Kappan, 86(6), 448–451. DOI: 10.1177/003172170508600608

McGinty, A.S., Breit-Smith, A., Fan, X., Justice, L.M., & Kaderavek, J.N. (2011). Does intensity matter? Preschoolers' print knowledge development within a classroom-based intervention. Early Childhood Research Quarterly, 26(3), 255–267. https://doi.org/10.1016/j.ecresq. 2011.02.002

McGraw-Hill Education. (2014). McGraw Hill Reading Wonders: CCSS reading/language arts program. New York, NY: Author.

Metsala, J.L., & Walley, A.C. (1998). Spoken vocabulary growth and the segmental restructuring of lexical representations: Precursors to phonemic awareness and early reading ability. In J.L. Metsala & L.C. Ehri (Eds.), Word recognition in beginning literacy (pp. 89–120). Mahwah, NJ: Erlbaum.

Moats, L.C., & Tolman, C. (2009). Language essentials for teachers of reading and spelling. Boston, MA: Sopris West.

Morris, R.D., Lovett, M.W., Wolf, M., Sevcik, R.A., Steinbach, K.A., Frijters, J.C., & Shapiro, M.B. (2012). Multiple-component remediation for developmental reading disabilities: IQ, socioeconomic status, and race as factors in remedial outcome. Journal of Learning Disabilities, 45(2), 99–127. https://doi.org/10.1177/0022219409355472

Muter, V., Hulme, C., Snowling, M.J., & Stevenson, J. (2004). Phonemes, rimes, vocabulary, and grammatical skills as foundations of early reading development: Evidence from a longitudinal study. Developmental Psychology, 40(5), 665–681. https://doi.org/10.1037/0012-1649. 40.5.665

National Conference of State Legislatures. (2019). Third-grade reading legislation. Retrieved from https://www.ncsl.org/research/education/third-grade-reading-legislation.aspx

National Institute of Child Health and Human Development. (2000). Report of the National Reading Panel. Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction (NIH Publication No. 00-4769). Washington, DC: U.S. Government Printing Office.

National Reading Panel. (2000). Teaching children to read: An evidencebased assessment of the scientific research literature on reading and its implications for reading instruction: Reports of the subgroups. Rockville, MD: National Institute of Child Health and Human Development.

Perfetti, C.A., & Hart, L. (2002). The lexical quality hypothesis. In L. Verhoeven, C. Elbro, & P. Reitsma (Eds.), Precursors of functional literacy (pp. 189–213). Amsterdam, Netherlands: John Benjamins.

Plaut, D.C. (2005). Connectionist approaches to reading. In M.J. Snowling & C. Hulme (Eds.), The science of reading: A handbook (pp. 24–38). London, UK: Blackwell.

Plaut, D.C., McClelland, J.L., Seidenberg, M.S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasiregular domains. Psychological Review, 103(1), 56–115. https://doi.org/10.1037/0033-295X.103.1.56

Ravitch, D. (2011). The death and life of the great American school system: How testing and choice are undermining education. New York, NY: Basic.

Rayner, K., Foorman, B.R., Perfetti, C.A., Pesetsky, D., & Seidenberg, M.S. (2001). How psychological science informs the teaching of reading. Psychological Science in the Public Interest, 2(2), 31–74. https://doi.org/10.1111/1529-1006.00004

Reardon, S.F. (2013). The widening income achievement gap. Educational Leadership, 70(8), 10–16.

Rumelhart, D.E. (1977). Toward an interactive model of reading. In S. Dornic (Ed.), Attention and performance VI (pp. 573–606). Hillsdale, NJ: Erlbaum.

Schuele, C.M., & Boudreau, D. (2008). Phonological awareness intervention: Beyond the basics. Language, Speech, and Hearing Services in Schools, 39(1), 3–20. https://doi.org/10.1044/0161-1461(2008/002)

Seidenberg, M.S. (2005). Connectionist models of word reading. Current Directions in Psychological Science, 14(5), 238–242. DOI: 10.1111/j.0963-7214.2005.00372.x

Seidenberg, M. (2017). Language at the speed of sight: How we read, why so many can't, and what can be done about it. New York, NY: Basic.

Seidenberg, M. (2019, December 6). This is why we don't have better readers: Response to Lucy Calkins [Web log post]. Retrieved from https://seidenbergreading.net/2019/12/06/lucy-calkins-on-the-attack/

Seidenberg, M.S., & McClelland, J.L. (1989). A distributed, developmental model of word recognition and naming. Psychological Review, 96(4), 523–568. https://doi.org/10.1037/0033-295X.96.4.523

Seidenberg, M.S., & Plaut, D.C. (2014). Quasiregularity and its discontents: The legacy of the past tense debate. Cognitive Science, 38(6), 1190–1228. https://doi.org/10.1111/cogs.12147

Seidenberg, M.S., & Zevin, J.D. (2006). Connectionist models in developmental cognitive neuroscience: Critical periods and the paradox of success. In Y. Munakata & M.H. Johnson (Eds.), Processes of change in brain and cognitive development: Attention and performance XXI (pp. 315–347). Oxford, UK: Oxford University Press.

Shanahan, T. (2004). Critiques of the National Reading Panel report: Their implications for research, policy, and practice. In P. McCardle & V. Chhabra (Eds.), The voice of evidence in reading research (pp. 235–265). Baltimore, MD: Paul H Brookes.

Shankweiler, D., Mencl, W.E., Braze, D., Tabor, W., Pugh, K.R., & Fulbright, R.K. (2008). Reading differences and brain: Cortical integration of speech and print in sentence processing varies with reader skill. Developmental Neuropsychology, 33(6), 745–775. https://doi. org/10.1080/87565640802418688

Share, D.L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. Cognition, 55(2), 151–218. https://doi. org/10.1016/0010-0277(94)00645-2

Smith, F. (1999). Why systematic phonics and phonemic awareness instruction constitute an educational hazard. Language Arts, 77(2), 150–155.

Snow, C.E., Burns, M.S. & Griffin, P. (Eds.). (1998). Preventing reading difficulties in young children. Washington, DC: National Academy Press. Snowling, M.J., & Hulme, C.E. (2005). The science of reading: A handbook. London, UK: Blackwell.

Stanovich, P.J., & Stanovich, K.E. (2003). Using research and reason in education: How teachers can use scientifically based research to make curricular and instructional decisions. Washington, DC: National Institute for Literacy.

Steacy, L.M., Elleman, A.M., Lovett, M.W., & Compton, D.L. (2016). Exploring differential effects across two decoding treatments on item-level transfer in children with significant word reading difficulties: A new approach for testing intervention elements. Scientific Studies of Reading, 20(4), 283–295. https://doi.org/10.1080/10888438.2016.1178267

Steiner, D.M., & Rozen, S.D. (2004). Preparing tomorrow's teachers: An analysis of syllabi from a sample of America's schools of education. In F.M. Hess, A.J. Rotherham, & K. Walsh (Eds.), A qualified teacher in every classroom? Appraising old answers and new ideas (pp. 119– 148). Cambridge, MA: Harvard Education Press.

Stuebing, K.K., Barth, A.E., Cirino, P.T., Francis, D.J., & Fletcher, J.M. (2008). A response to recent reanalyses of the National Reading Panel report: Effects of systematic phonics instruction are practically significant. Journal of Educational Psychology, 100(1), 123–134. https://doi.org/10.1037/0022-0663.100.1.123

Ueno, T., Saito, S., Rogers, T.T., & Ralph, M.A.L. (2011). Lichtheim 2: Synthesizing aphasia and the neural basis of language in a neurocomputational model of the dual dorsal-ventral language pathways. Neuron, 72(2), 385–396. https://doi.org/10.1016/j.neuron.2011.09.013

Vellutino, F.R., Tunmer, W.E., Jaccard, J.J., & Chen, R. (2007). Components of reading ability: Multivariate evidence for a convergent skills model of reading development. Scientific Studies of Reading, 11(1), 3–32. https://doi.org/10.1080/10888430709336632

Vousden, J.I., Ellefson, M.R., Solity, J., & Chater, N. (2011). Simplifying reading: Applying the simplicity principle to reading. Cognitive Science, 35(1), 34–78. https://doi.org/10.1111/j.1551-6709.2010.01134.x

Table 1

Future Steps in Relating the Science of Reading to Educational Practice

Step 1. Pursue cross-disciplinary collaborations Summarizing findings and expecting others to pursue the implications has not been an of individuals with complementary types of expertise. Translating reading science into verifiably effective educational practices does as well. Such teams are more likely to succeed at employing basic insights about reading and learning in ways that can be utilized by educators in the classroom.
Step 2. Work toward a new science of teaching The goal of a research-based science of teaching is to identify effective instructional practices given a specification of what needs to be learned (skills and types of knowledge), at different points in development, for children who differ in ways that affect progress. Proposed practices are hypotheses about effective instruction whose validity must be empirically assessed.
Step 3. Avoid a narrow focus on phonics Discussions about connecting the science of reading to education are often limited to phonics. The considerable research on this issue is only one part of a much larger body of research that has addressed the many other elements of skilled reading and its development, including the many factors that affect students' progress. The science speaks to the importance of integrating print and sound early in development and to the role of instruction. However, it does so in the context of other skills and knowledge, their dependence on each other, and the development of reading over time.
Step 4. Invest in early learning Many students are at risk for reading difficulties on the first day of school (Loeb & Bassok, 2008), largely because of individual differences in knowledge of spoken language and the world that it is used to communicate about (Hoff, 2013; Muter, Hulme, Snowling, & Stevenson, 2004). Increased translational research about what can be done in early learning contexts prior to the start of school will help fill in knowledge of what can be done, when, and for which learners.
Step 5. Develop a science of reading that applies to all readers Most research on the science of reading has been conducted with individuals from a narrow range of backgrounds. Conclusions based on this research cannot be assumed to generalize to understudied groups, including racial/ethnic minorities and individuals from low-income backgrounds. Deeper understanding of the impact of these individual difference factors is necessary to advance the science and its impact on education.
Step 6. Examine existing systems of learning Curricula and instruction can be assessed with respect to whether they are consistent with basic facts about reading and development derived from modern science. Existing systems, from formal curricula to informal practices, should be examined and augmented in ways that move them closer to what we know about how learners learn.