Waterford Research Institute, LLC

The Science of Reading: From Research to Instruction

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In 1998, the National Research Council wrote that “the demands for higher literacy are ever increasing, creating more grievous consequences for those who fall short.” More than twenty years later, this is increasingly true. In addition, too much reading instruction is based on “outdated assumptions about reading and development that make learning to read harder than it needs to be, a sure way to leave many children behind” (Seidenberg, 2014, p. 340).

Despite the fact that 34% of American 4th graders read below a basic level (The Nation's Report Card, 2019), many empirical studies show that “a large proportion of students at risk for reading difficulties, as well as students with severe reading disabilities, can develop and maintain normalized reading skills when provided with the right intervention” (Kilpatrick, 2015). A convergence of brain science with education science helps to identify the key elements of effective reading instruction that can bring to fruition the vision of universal literacy. The power to leverage the science is in hand.

Modern Neuroscience: How the Brain Learns to Read

Learning to speak unfolds naturally through exposure to oral language. By contrast, learning to read requires several years of intentional instruction. In other words, the human brain is wired for speech but must be deliberately trained to read. Today, we are living in the midst of what neuroscientist Stanislas Dehaene calls a “neuroscientific revolution” in which emerging brain imaging technologies increasingly reveal how the brain’s reading network works. This new information about how we become readers must inform best practices for instruction. An introductory view of how the brain learns to identify written words in three stages—pictorial, phonological, and orthographic (Frith, 1985)—provides a good starting point.

As they acquire spoken language, young children learn the pronunciations and meanings of thousands of words. This information is stored in separate areas of the brain (Willingham, 2017), represented by the meaning and oral language puzzle pieces in Figure 1. As they begin to attend to printed language, and before they have extensive knowledge of letter-sound relationships, children enter the pictorial stage of word identification.

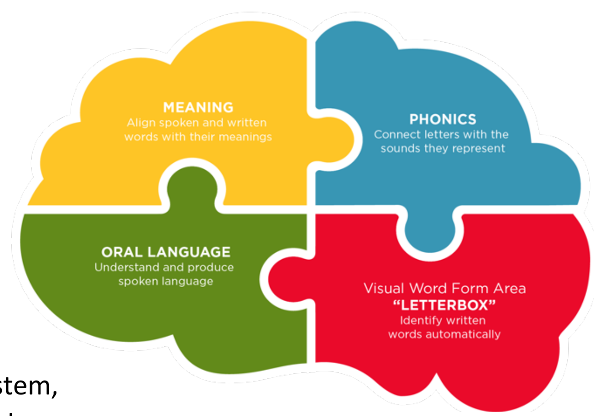

Figure 1: The Brain’s Reading Network

During this stage, children rely heavily on the brain’s visual system, perceiving words as pictures or objects with little or no regard to letters and the sounds they represent. They learn to identify a limited number of words based on their overall visual appearance, often depending on fonts, color, and logos typically associated with those words (think environmental print such as *stop* or *McDonald’s*). In a similar way, students may also identify some high-frequency words (*me*, *the*, etc.) or familiar words such as their own name. The processes that characterize the pictorial stage are insufficient for the development of proficient reading. The lack of correlation between visual memory tasks and word-level reading tasks (Kilpatrick, 2015) is evidence that reading is not simply a visual task. Learning to read in an alphabetic system such as English requires the coordination of additional systems within the brain.

During the phonological stage, children decode words. They isolate individual letters within a word and associate them with speech sounds in "grapheme to phoneme" conversions. This allows the child to identify the pronunciation of the printed word (retrieved from the oral language area of the brain), which then activates its meaning. Connections between these areas of the brain are not prewired. Neural pathways must be established through effective instruction and extensive practice. The child is now reading, but the ability to decode print is still not sufficient to produce fluent reading.

Finally, in the orthographic stage, children learn to recognize an increasing number of words automatically, freeing the brain from the cognitive load required for decoding those words letter by letter. What makes this shift from methodical decoding to instant recognition of words possible? The answer is that learning to read literally changes the brain. In response to the unique demands presented by reading acquisition, a specialized area is developed within the brain's visual system—the visual word form area, dubbed the "letterbox" by Stanislas Dehaene (2009). Learning to read "transform[s] some of the visual structures of our brain in order to turn them into a specialized interface between vision and language" (Dehaene, 2011, p. 20).

The brain's letterbox supports the process of orthographic mapping, the process that permanently bonds the speech sounds in a word (phonemes) with the spellings of those sounds (graphemes) and anchors the word's spelling to its pronunciation and meaning in long-term memory. The word is now a sight word for the reader; it is instantly recognizable and no longer requires decoding.

As a result of the mapping process, a proficient reader can instantly recognize between 30,000 and 80,000 words (Moats, 2010). Again, the necessary neuronal pathways for this process are not pre-paved. They must be forged through instruction and practice. With increased reading experience, activity in the area of the brain that supports decoding (represented by the phonics puzzle piece in Figure 1) decreases as activity in the letterbox (central to the mapping process) increases. It is important to note that orthographic memory is not visual memory. Instead, it is letter-by-letter, sound-symbol memory. Studies reveal that even the most fluent readers still attend to every letter in every word (Kilpatrick, 2015).

In summary, when a reader encounters a novel word, they rely on decoding to identify it. After the word is identified, its pronunciation and then its meaning are activated. When the same reader encounters a word that has already been added to long-term memory through the orthographic mapping process, the word is instantly recognized, automatically activating the pronunciation and then the meaning of the word. (See Figure 2). The orthographic mapping process makes fluent reading possible.

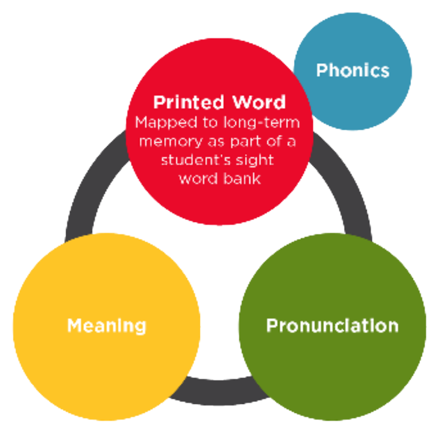

Figure 2: How the Brain Identifies Written Words: When a word is part of a student's sight word bank, it is permanently linked to the word's pronunciation and meaning. The word is recognized instantly. When a student encounters a word that has not been added to their sight word bank through the orthographic mapping process, they rely on their knowledge of phonics to decode and identify the word.

At the age when children typically begin to read, their brains are maximally plastic. With the "right type of training" (Shaywitz & Shaywitz, 2020), the process of learning to read creates anatomical, bi-directional pathways between the visual areas and language areas of the brain's left hemisphere. In the words of Maryann Wolf, "We can learn to read only because the brain has this capacity to change" (Wolf, 2007).

Neuroscience sheds light on the reading process within the brain. But what does education research that aligns with the findings of neuroscience tell us about the nature of effective reading instruction? Next, we will examine two instructional frameworks that explain the reading process from the viewpoint of educators.

Two Frameworks That Align With the Science

Two frameworks, the Simple View of Reading and Scarboroughs' Reading Rope, are particularly helpful. These frameworks align well with modern neuroscience research despite the fact that they pre-date much of that research.

Developed by Gough & Tunmer (1986), the Simple View of Reading states that reading comprehension is the product of word recognition and language comprehension (which equates roughly to a child's level of listening comprehension). Struggles in either or both of these areas will negatively affect reading comprehension. The Simple View formula is referenced widely by those who seek to align instruction with the science of reading. Recent research has confirmed that word recognition and language comprehension do in fact account for almost all variance in reading comprehension (Lonigan et al., 2018).

Figure 3: The Simple View of Reading

Scarborough's Reading Rope (Scarborough, 2001) elaborates on the Simple View by identifying component skills within the two domains of word recognition and language comprehension. Foundational word recognition skills are woven together to support increasingly automatic reading, while language comprehension skills work together so that reading can become increasingly strategic.

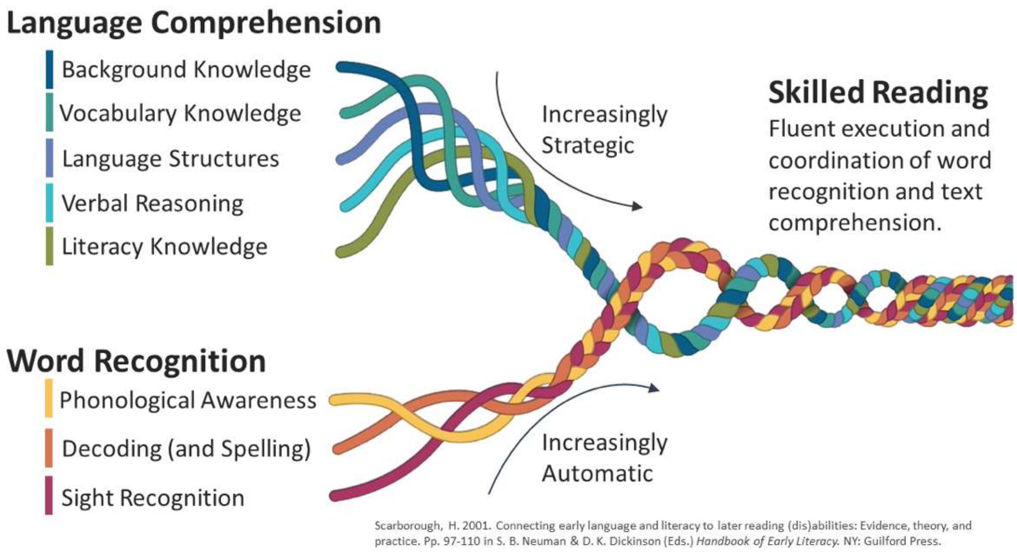

Figure 4: Scarborough's Reading Rope

Waterford.org: Equity & Access

The nonprofit Waterford.org was founded in 1976 (as Waterford Research Institute) with the vision of achieving universal literacy by fostering equity and providing access to quality research-based early-literacy instruction. The Waterford Early Learning program, developed beginning in the early 1990s, was first released in 1998, providing a comprehensive, adaptive digital reading curriculum for pre-kindergarten through 2nd-grade students.

The initial content for Waterford Early Learning was developed in consultation with Dr. Marilyn Jager Adams and in alignment with the principles set forth in her landmark book Beginning to Read: Thinking and Learning About Print (1990). In addition, recommendations from the National Research Council (1998), the National Reading Panel (2000), the National Early Literacy Panel (2008), and the What Works Clearinghouse (WWC) K–3 Reading Practice Guide (Foorman et al., 2016) have guided Waterford's curriculum development. These major research syntheses emphasize the importance of phonological awareness, phonics, vocabulary, fluency, and comprehension as critical components of effective reading instruction. Through the years, Waterford has relied on the work of many experts in the field of education including Ehri, Torgersen, Stanovich, Snow, Beck, Moats, and Kilpatrick.

Today, the model is the same—providing children with effective instruction while empowering the educators and families that support them in their learning journeys. All of Waterford's educational content is now offered under the umbrella of the Waterford Reading Academy, and the mission continues—to blend the best aspects of learning science, mentoring relationships, and innovative technologies to form community, school, and home programs that deliver excellence and equity for all learners.

Waterford Curriculum: Research in Action

An Overview

In alignment with Scarborough's Reading Rope, Waterford's curriculum provides carefully-sequenced learning experiences that lead to proficient *word recognition*. Students develop phonological awareness and phonics skills; they combine those skills to develop reading fluency through the process of orthographic mapping. In parallel, the program fosters *language comprehension* through the development of vocabulary and background knowledge. Frequent opportunities to read interactive, connected texts (decodable, narrative, and informational) support the development of literacy knowledge and verbal reasoning as well as familiarity with language structures.

Waterford's instruction is explicit, systematic, cumulative, diagnostic, and responsive (National Reading Panel, 2000). The program provides direct instruction, guided and independent practice, prompt feedback, scaffolding, distributed practice, and ongoing review (Spear-Swerling, 2018). Instruction is delivered at a brisk pace, and student responses are elicited frequently to maximize engagement.

Progression is mastery based, and embedded assessment drives adaptive learning pathways for individual students. Actionable data highlights achievements and identifies areas of struggle, allowing teachers to provide targeted support, including whole class, small group, and individual interventions.

Waterford's curriculum is infused with content that supports the development of healthy Mindset Skills—executive function, social-emotional learning, and growth mindset. These factors are of central importance in the process of learning to read. For example, a student must be able to attend to instruction in order to benefit from it (executive function), must know when and how to attend (self-awareness), must understand the importance of learning to read (social awareness), and must believe that, through their own effort, they can succeed (growth mindset).

Waterford's Six Instructional Strands for Literacy

Waterford's six instructional strands for literacy incorporate the essential components of reading as identified by the National Reading Panel (2000). Additional strands—Language Concepts and Communication—help students understand how written language is organized and develop their writing, speaking, and listening skills.

Figure 5: Waterford's Six Instructional Strands for Literacy

[Waterford.org Phonological Awareness Fact Sheet]

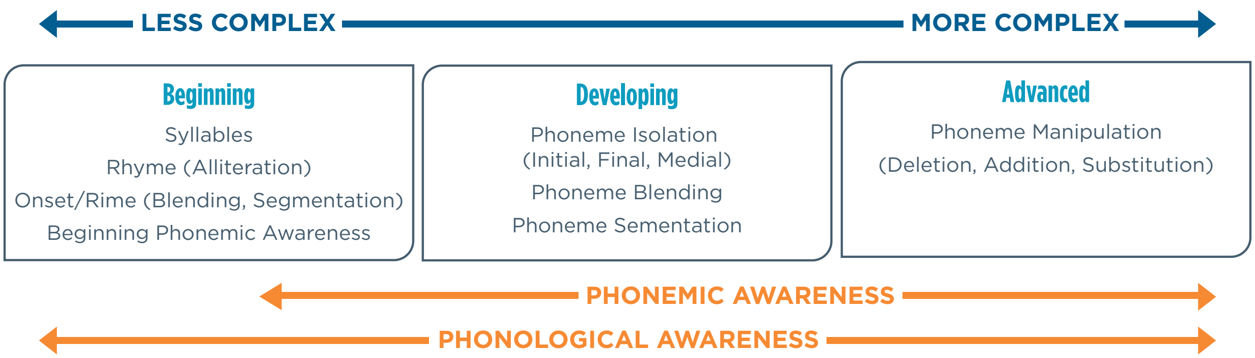

Figure 6: Developmental Overview—Phonological Awareness

The foundational importance of phonological awareness—and phonemic awareness, the subset of skills that involve phonemes, the smallest units of sound in spoken language—is clear (see Adams, 1990; National Reading Panel, 2000; National Early Literacy Panel, 2008; Kilpatrick, 2015; Foorman et al., 2016). English is an alphabetic system in which speech sounds are represented by letters. To break the reading code, children must be able to hear units of sounds within speech and connect these sounds with the letters that represent them. "Just as proteins must first be broken down into their underlying amino acids before they can be digested, words must first be broken down into their underlying phonemes before they can be processed by the language system" (Shaywitz & Shaywitz, 2020, p. 42). Studies have shown that even for high school students, phonemic awareness is the best predictor of students' ability to identify words quickly and accurately (Shaywitz & Shaywitz, 2020).

Because oral language is experienced as a continuous stream of speech, breaking it into smaller units of sound is not intuitive—these skills must be taught explicitly to support the development of literacy. The challenge is significant. Phonemes overlap in speech, and individual sounds can be altered slightly by the sounds that come before and after them (Castles et al., 2018; Willingham, 2017; Moats, 2010). In support of proficient reading, students must master the most advanced phonemic awareness skills—phoneme manipulation. Older struggling readers often lack these most advanced phonemic awareness skills (Kilpatrick, 2015).

[Waterford.org Phonics Fact Sheet](#)

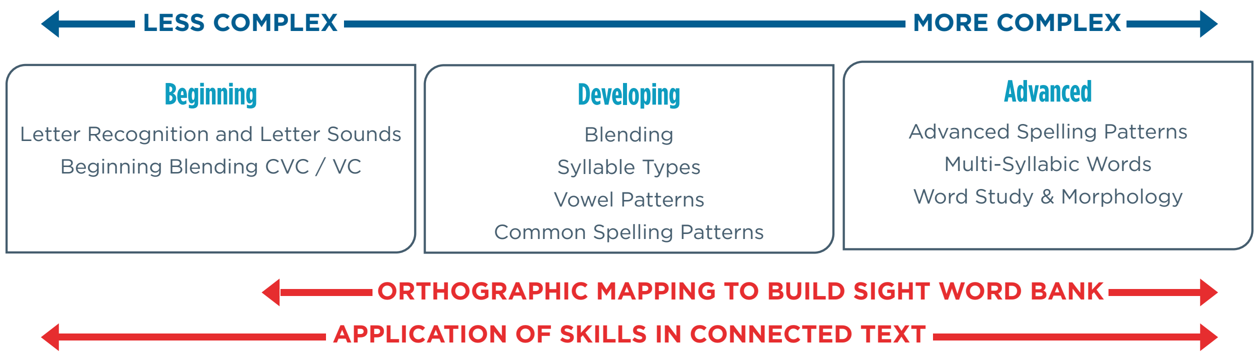

Figure 7: Developmental Overview—Phonics

“Phonics is crucial because it gives children the skills to translate orthography into phonology and thereby to access knowledge about meaning” (Castles et al., 2018, p. 15). Early phonics instruction focuses on alphabet knowledge, the development of automatic letter recognition, and the understanding of basic letter-sound correspondences. Alphabet knowledge was identified by the National Early Literacy Panel as a key predictor of later outcomes (2008). To make sense of alphabet knowledge, students must understand the underlying alphabetic principle—the idea that speech sounds are represented by letters in systematic and predictable ways. This principle is not intuitive; children do not discover it independently (Willingham, 2017; et al., 2018). Beginning readers must be taught “how to relate a new code, written script, to an existing code, spoken language” (Seidenberg, 2014, p. 331).

Students can begin to blend sounds to decode words when they have mastered several letter-sound correspondences. Word-building practice should be an integral part of instruction as students acquire knowledge of simple and complex phonics patterns, syllable types, and rules for syllable division. Throughout, students need frequent opportunities to apply and reinforce their learning by reading decodable texts.

Because readers do not process words as a whole, but rather process all the information represented by individual letters (Adams, 1990), explicit and systematic phonics instruction is central to learning to read. Although English orthography is complex, Solity and Vousden (2009) reported that knowledge of the sixty-four most common letter-sound correspondences, together with the ability to identify approximately 100 of the most common words, enables young readers to identify 90% of words they tend to see in texts.

[Waterford.org Fluency Fact Sheet]

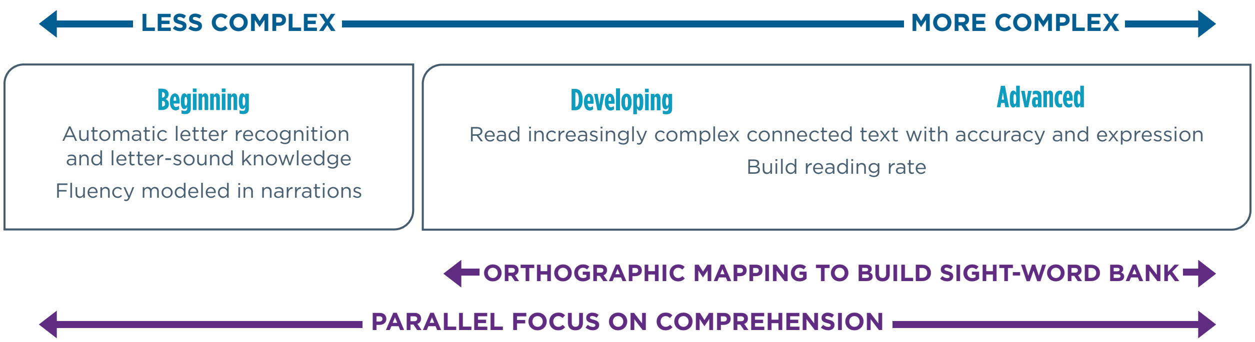

Figure 8: Developmental Overview—Fluency

Proficient readers perceive words in 1/20th of a second and can read at a rate of 150–250 words a minute (Kilpatrick, 2015). This level of fluency is possible only when students have developed a large bank of sight words—words that can be recognized instantly—without the need to decode. Words are added to a student's sight word bank, transformed from unfamiliar to instantly accessible, through the process of orthographic mapping. Once a word is mapped, its spelling, pronunciation, and meaning are bonded together in long-term memory. With more information stored in long-term memory, the cognitive load on short-term memory is decreased.

A growing body of research (see Share, 1999; Share, 2004; Kilpatrick, 2015) shows that when typically developing readers become reasonably proficient at mapping words, they begin to self-teach. Through repeated exposure to a given word, mapping occurs naturally. Orthographic knowledge related to that word is then available for future encounters with the word and similar words, decreasing the student's reliance on decoding (Castles et al., 2018). Because multiple exposures to words build fluency, asking students to engage in repeated reading of appropriately challenging texts is an effective way to support the word mapping process.

This process works equally well for regularly and irregularly spelled words. New words are typically added to the brain's lexicon after one to four exposures. For irregularly spelled words, just one to two extra exposures are needed for typical readers. The brain makes mapping "adjustments" to account for irregularities in letter-sound correspondence.

[Waterford.org Comprehension & Vocabulary Fact Sheet](#)

LESS COMPLEX ⟶ MORE COMPLEX

Beginning	Developing	Advanced

Develop language comprehension through purposeful conversation and engaging read-alouds.
Build vocabulary and background knowledge.
Increase reading fluency so that students can focus on the meaning of texts.
Teach comprehension strategies.
Foster critical thinking skills through rich reading experiences with narrative and informational text.

Figure 9: Developmental Overview—Comprehension & Vocabulary

Although some controversy surrounds studies on the issue, the "word gap" describes a disparity between exposure to oral language in the early years of life for children from language-rich home environments as compared with some of their peers (Golinkoff et al., 2019; Sperry et al., 2019; Hart & Risley, 1995). This disparity creates both a vocabulary gap and a background knowledge gap (Snow, 2017). Vocabulary knowledge and background knowledge are closely linked, and they are both important contributing factors for reading comprehension (Adams, 1990; Scarborough, 2001). The issue of early oral language exposure is complex, and levels of exposure are not strictly correlated with socio-economic status or with the particular languages spoken in homes. In addition, the quality of the language children hear matters as much or more than the quantity of language (Snow, 2017).

In the interest of building vocabulary knowledge and background knowledge, experts recommend combining content instruction and reading instruction (Cabell & Hwang, 2020; Petscher et al., 2020). Content knowledge supports the ability to make inferences, a key component of reading comprehension (Cabell & Hwang, 2020).

Vocabulary instruction should focus on academic vocabulary and "tier 2" words, those words that are commonly seen in narrative and informational texts but whose meanings may not be part of students' oral vocabularies. New words should be introduced with student-friendly definitions, experienced in multiple contexts, and learned through repeated exposures (Beck et al., 2002). Morphology instruction creates bridges between meaning and spelling (Castles et al., 2018) and supports reading comprehension (Kilpatrick, 2015).

Research shows that teaching comprehension skills and strategies such as making predictions, generating questions, summarizing, understanding text structure, and using graphic organizers is helpful (see National Reading Panel, 2000; Castles et al., 2018; Kilpatrick, 2015). However, these strategies and skills cannot compensate for limitations in vocabulary knowledge or content knowledge (Kilpatrick, 2015). Teaching students to monitor their own comprehension and take action to mend lapses in their comprehension is also effective (National Reading Panel, 2000).

All of this should happen in the context of purposeful reading of high-quality, authentic texts.

[Waterford.org Language Concepts Fact Sheet]

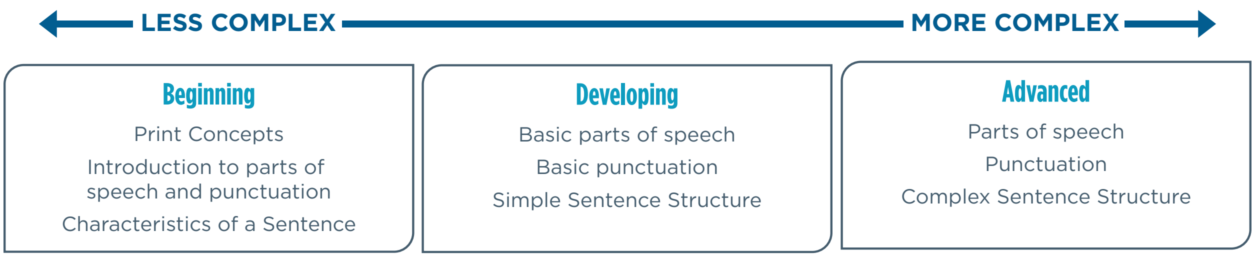

Figure 10: Developmental Overview—Language Concepts

The language concepts strand helps students understand how written language is organized and is roughly equivalent to the literary knowledge and language structures strands of the Reading Rope.

As part of a strong foundation for learning to read, students must develop print awareness (Adams, 1990). Through experience with print, its nature and uses are revealed to young learners. They see how written language corresponds to spoken language and perceive that readers follow print from left to right. They learn that spaces separate words and begin to understand how punctuation separates ideas. They become familiar with a variety of genres and types of text. They discover many purposes for reading.

Later, students learn to encode, or spell, according to the conventions of English orthography. This happens in parallel with the decoding instruction they experience in the phonics strand. In the words of Linnea Ehri, spelling and reading are “mutually facilitative and reciprocal” (2000, p. 34). There is also clear overlap here with the fluency strand—decoding and encoding are both part of the orthographic mapping process.

As developing readers, students build knowledge of grammar, including how sentences are structured and how to identify parts of speech. Research shows that an understanding of grammar supports reading comprehension (Silva & Cain, 2015).

[Waterford.org Communication Fact Sheet]

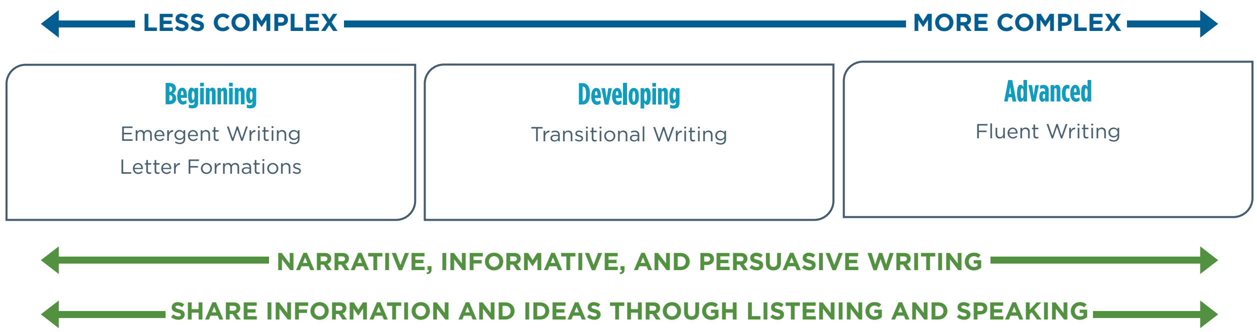

Figure 11: Developmental Overview—Communication

The communication strand addresses the speaking, listening, and writing domains of language development. Proficiency in these domains enables students to share information and ideas with others. Below are some observations about how they relate to each other and to the development of skilled reading.

Speaking

Early oral language skills are a strong predictor of later outcomes related to reading comprehension (e.g., Hart & Risley, 1995; National Early Literacy Panel, 2008). Students need oral communication experiences in which "language is linked to content, in which knowledge structures are built and elaborated and in which, because they get answers to the questions they pose, children become increasingly curious" (Snow, 2017). Extensive oral language experience builds verbal reasoning, one of the strands in Scarborough's Rope (2001), and supports students' ability to make inferences. Oral language skills play a role in learning to read, and reading plays a role in the development of oral language skills (Seidenberg, 2014).

Listening

Listening is the mirror of speaking. Listening comprehension (or language comprehension) is one of two domains represented in Scarborough's Reading Rope (2001). The role of listening skills in the development of reading comprehension is clear. Read-aloud experiences provide students with opportunities to build their listening and comprehension skills and act as models for fluent reading.

Writing

The National Early Literacy Panel identified "the ability to write letters in isolation on request or to write one's own name" as an early literacy skill that is predictive of later reading outcomes (National Early Literacy Panel, 2008). Dehaene explains that "teaching the gestures of writing can improve reading, perhaps because it helps store view-specific memories of the letters and their corresponding phonemes" (2011, p. 28). Transcription skills are essential for the development of writing fluency and are a contributor to the development of word recognition for reading.

Studies show that reading and writing require many of the same cognitive processes and types of knowledge (Shanahan, 2016). Good readers are better writers, and good writers are better readers.

Toward Universal Literacy

Cognitive scientist Mark Seidenberg observes that “there is remarkable consensus about the basic theory of how reading works and the causes of reading successes and failures” (2014, p. 332). This consensus among experts in brain science and education research provides a solid foundation on which we must build effective instruction. We know what happens inside the brains of developing and proficient readers. We understand the processes and skills that are required for automatic and strategic reading. We have identified the types of instruction that are most effective. Universal literacy is necessitated by today’s society, and it is within reach.

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