# The Science of Reading

## What is the Science of Reading?

The science of reading refers to a body of research from the fields of education, cognitive psychology, developmental psychology, and neuroscience, that explains how individuals learn how to read and best practices for reading instruction[1, 2]. Recent advances in technology and a greater understanding of neurobiology have allowed researchers and practitioners who work with typical and struggling readers to understand how reading develops in the brain and the skills that contribute to proficient reading. It is important for educators to understand this body of research because it directly affects how reading is taught and using methods that are not aligned with research can have a negative impact on students' reading achievement. As such, *the purpose of this section of the toolkit is to provide a brief overview of this body of research and provide additional resources for educators and other practitioners to explore.*

## Areas of the Brain Involved in Reading

A common misconception about reading is that all humans "learn to read in a different way." Although reading is a relatively recent cultural invention, the human brain is not prewired to learn to read naturally[3]. Neurobiological research has demonstrated that reading is a complex process that occurs in three different but connected areas of the brain[1,4]. These three areas work together to help individuals read words:

- Frontal Lobe – the inferior frontal gyrus in the frontal lobe is responsible for grammatical and speech processing, in addition to information about the sounds in words
- Temporoparietal Area – responsible for processing and storing speech sounds; where phonemes (sounds) are connected to graphemes (letters); also involved in word and sentence meanings
- Occipitotemporal Area – processes visual information (e.g., letters, words)

Imaging studies, such as fMRI studies, show that these different areas of the brain are activated during reading[4]. There are two main pathways of the brain that are activated during reading:

1. Dorsal Pathway – activated during decoding/sounding out
2. Ventral Pathway – activated when words are read by sight (i.e., automatically without sounding out)

Struggling readers, including students with dyslexia, activate *different* pathways and areas of their brain than proficient readers do, which causes these students to use

other, *less efficient*, areas of their brain to read words[4]. Despite this, high-quality evidence-based instruction and intervention can actually "rewire" the brains of students with dyslexia so that they can use more efficient areas and pathways to read[5].

**The Simple View of Reading and Scarborough's Reading Rope**

In the Simple View of Reading (SVR), reading comprehension is conceptualized as the product of two component skills: decoding and linguistic comprehension[6,7]. Decoding, a word-level skill, involves rapidly and efficiently retrieving words from memory, and linguistic comprehension consists of the literal and inferential construction and interpretation of the meaning of those words[7,8]. If an individual is able to decode words, but does not understand what those words mean, then they will not be able to comprehend a text. Conversely, if an individual is able to understand what words mean, but not decode them, they will also not be able to comprehend text. Because many students with dyslexia have difficulties with decoding, they are likely to have difficulty comprehending text. This does NOT mean that reading is a simple process, only that two main components (decoding and linguistic comprehension) contribute the most to overall reading comprehension. Click here to view an infographic about the Simple View of Reading.

Scarborough (2001)[9] created a graphic called the "Reading Rope" that depicts the components of the SVR. To become a skilled reader, a student must develop increasing speed and accuracy in decoding and linguistic comprehension skills[9]. Specifically, automatic decoding frees up an individual's attentional resources so that they can comprehend text. To reach this level of automaticity, students require proper instruction that focuses on mastering decoding skills. Due to copyright reasons, we cannot reprint the graphic in this toolkit; however, click here to view the reading rope and the International Dyslexia Association's accompanying explanation.

**Word-Reading and Spelling Development**

In order for students to be able to accurately and automatically decode words, they need to learn that that writing is a symbolic system used to represent spoken language and the smallest units of language (phonemes) are represented by print (also known as the *alphabetic principle*)[10,11]. While acquiring the alphabetic principle, individuals progress through several stages of alphabetic decoding, in which they learn to map phonemes to graphemes[10,12,13]. Ehri's (1998)[12] stage model of reading development describes these progressive stages as follows:

- Pre-Alphabetic – pre-reading stage where individuals do not make letter-to-sound connections; "reading" is based on visual cues
- Partial Alphabetic – individuals begin to connect some phonemes to graphemes, but these representations are not complete

- Full Alphabetic – individuals develop more complete representations of words and their phoneme-grapheme relationships
- Consolidated Alphabetic – individuals have acquired a large bank of words they can read by sight (i.e., automatically and accurately) and now recognize larger units of language in words such as syllables and morphemes

Individuals progress through similar stages for spelling[11,14]; however, spelling is often more difficult for individuals to acquire than word-reading[14,15,16,17]. Spelling requires individuals to learn to visually identify letters by their shape and to physically produce those shapes[11]. Proficient spelling also requires individuals to acquire in-depth knowledge about the structure of the English language system[14]. Spelling proficiency is acquired by learning about different patterns in words:

- Phonological (Sound) Patterns – understanding of the sounds in words
- Graphotactic (Written) Patterns – how words are written or represented in print
- Morphological (Structure) Patterns – understanding the meanings of words or parts of words

Word-reading is also acquired and enhanced through an individual's spelling development. As an individual repeatedly associates phonemes to graphemes and larger units of language (i.e., orthographic mapping), these association become engrained in the memory and easier to retrieve with automaticity[12,13].

**Accurate and Automatic Word-Reading**

Although individuals initially learn to read by activating the dorsal pathway in the brain to decode words, the dorsal pathway is slower and less automatic than the ventral pathway where words are read by sight. There are two key processes necessary for accurate and automatic sight-word reading (i.e., proficient word-reading):

1. connecting a word's pronunciation to its meaning and spelling; and
2. connecting a word's meaning to its spelling, so that it can be read without going through the phonological system which slows down the process[10,13,18].

Proficient word-reading occurs when a word's pronunciation is associated with its meaning and its written spelling[13,14,18]. With practice, individuals begin to automatically connect words' pronunciations, meanings, and spellings and this allows an individual's speed and accuracy to improve[19,20]. This also helps individuals bypass the slower and less efficient dorsal/decoding pathway. This allows the cognitive resources (i.e., working memory) to be allocated to reading comprehension[21,22,23]. If individuals do not become accurate and automatic word-readers, then they must constantly rely on the slower dorsal pathway to decode words, which can cause difficulties with spelling, word-reading, and text comprehension[10,20].

## Linguistic/Language Comprehension

Accurate and automatic word-reading alone is not sufficient for individuals to be able to comprehend text. Proficient reading comprehension also requires the reader to be able to comprehend language[6]. Language comprehension requires in-depth knowledge of morphology, semantics, syntax, background knowledge, verbal reasoning, and literacy knowledge[3,9]. Morphology is the study of the smallest units of language that have meaning (i.e., prefixes, suffixes, roots, base words). Semantics (vocabulary) involves the meaning of words, phrases, and sentences. Syntax includes grammatical structure and parts of speech.

## The Five Components of Reading

How does all of this information relate to the five "components" of reading, as identified by the National Reading Panel's (NRP's) report on reading instruction[24]? Although the NRP identified five "components" of reading instruction from research (phonemic awareness, phonics, fluency, vocabulary, and reading comprehension), it is important to note that each of these "components" are highly connected and should not be taught as distinct skills[25]. For example, phonological awareness, phonics, and word-reading fluency are a part of decoding or word-recognition in the SVR, whereas vocabulary is a part of linguistic comprehension. These components are typically taught together in a comprehensive literacy program. The five "components" are described below[3,24]:

- Phonemic Awareness – the ability to identify, think about, and manipulate the smallest sounds (phonemes) in language
- Phonics – a method for teaching phoneme-grapheme correspondences for reading and spelling
- Fluency – the ability to read a text accurately, automatically, and with expression
- Vocabulary – understanding and using words in oral and written language
- Comprehension – the ultimate goal of reading; understanding what is read

## Additional Resources about The Science of Reading

Additional resources (e.g., books, articles, websites, learning modules) about the Science of Reading are available in the Science of Reading Resources section of this toolkit. These resources are not endorsed by the Indiana Department of Education or Indiana University.

## References

1. Gentry, J. R., & Ouellette, G. P. (2019). *Brain words: How the science of reading informs teaching.* Stenhouse.
2. Petscher, Y., Cabell, S. Q., Catts, H. W., Compton, D. L., Foorman, B. R., Hart, S. A., Lonigan, C. J., Phillips, B. M., Schatschneider, C., Steacy, L. M., Terry, N. P., & Wagner, R. K. (2020). How the science of reading informs 21st century education. *Reading Research Quarterly, 55*(S1), S267-S282. https://doi.org/10.1002/rrq.352
3. Moats, L. C. (2020). *Speech to print: Language essentials for teachers* (3rd ed.). Brookes.
4. Kearns, D. M., Hancock, R., Hoeft, F., Pugh, K. R., & Frost, S. J. (2019). The neurobiology of dyslexia. *TEACHING Exceptional Children, 51*(3), 175-188. https://doi.org/10.1177/0040059918820051
5. Barquero, L. A., Davis, N., & Cutting, L. E. (2014). Neuroimaging of reading intervention: A systematic review and activation likelihood estimate meta-analysis. *PLoS ONE, 9*, e83668-16. https://doi.org/10.1371/journal.pone.0083668
6. 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
7. Hoover, W. A., & Gough, P. B. (1990). The simple view of reading. *Reading and Writing, 2*, 127-160. https://doi.org/10.1007/BF00401799
8. Hoover, W. A., & Tunmer, W. E. (2018). The simple view of reading: Three assessments of its adequacy. *Remedial and Special Education, 39*(5), 304-312. https://doi.org/10.1177/0741932518773154
9. Scarborough, H. S. (2001). Connecting early language and literacy to later reading (dis)abilities: Evidence, theory, and practice. In S. Neuman & D. Dickinson (Eds.), *Handbook for research in early literacy* (pp. 97–110). Guilford Press.
10. Castles, A., Rastle, K., Nation, (2018). Ending the reading wars: Reading acquisition from novice to expert. *Pyschological Science in the Public Interest, 19*(1), 5-51. https://doi.org/10.1177/1529100618772271
11. Treiman, R., & Kessler, B. (2005). Writing systems and spelling development. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 120-134). https://doi.org/10.1002/9780470757642.ch7
12. Ehri, L. C. (1998). Grapheme-phoneme knowledge is essential for learning to read words in English. In J. L. Metsala & L. C. Ehri (Eds.), *Word recognition in beginning literacy* (pp. 3-40). Taylor and Francis. http://ebookcentral.proquest.com/lib/iub-ebooks/detail.action?docID=474573

13. Ehri, L. C. (2005). Learning to read words: Theory, findings, and issues. *Scientific studies of reading, 9*(2), 167-188. https://psycnet.apa.org/doi/10.1207/s1532799xssr0902_4
14. Treiman, R. (2017). Learning to spell words: Findings, theories, and issues. *Scientific Studies of Reading, 21*(4), 265-276. https://doi.org/10.1080/10888438.2017.1296449
15. Bosman, A. M. T., & Van Orden, G. C. (1997). Why spelling is more difficult than reading. In C. A. Perfetti, L. Rieben, & M. Fayol (Eds.), *Learning to spell: Research, theory, and practice across languages* (pp. 173-194). Lawrence Erlbaum.
16. Perfetti, C. A. (1997). The psycholinguistics of spelling and reading. In C. A. Perfetti, L. Rieben, & M. Fayol (Eds.), *Learning to spell: Research, theory, and practice across languages* (pp. 21-38). Mahwah, NJ: Lawrence Erlbaum.
17. Ehri, L. C. (2000). Learning to read and learning to spell: Two sides of a coin. *Topics in Language Disorders, 20*(3), 19-36.
18. 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
19. Ehri, L. C. (2014). Orthographic mapping in the acquisition of sight word reading, spelling memory, and vocabulary learning. *Scientific Studies of Reading, 18*(1), 5-21. https://doi.org/10.1080/10888438.2013.819356
20. Perfetti, C. (2007). Reading ability: Lexical quality to comprehension. *Scientific Studies of Reading, 11*(4), 357-383. https://doi.org/10.1080/10888430701530730
21. Fletcher, J. M., Lyon, R. G., Fuchs, L. S., & Barnes, M. A. (2019). *Learning disabilities: From identification to intervention* (2nd ed.). Guilford Press.
22. LaBerge, D. & Samuels, S. J. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology, 6*(2), 293-323. https://doi.org/10.1016/0010-0285(74)90015-2
23. Perfetti, C. A. (1985). *Reading ability.* Oxford University Press.
24. National Institute of Child Health and Human Development (2000). *National reading panel—Teaching children to read: Reports of the subgroups* (NIH Pub. No. 00-4754). U.S. Department of Health and Human Services. https://www.nichd.nih.gov/sites/default/files/publications/pubs/nrp/Documents/report.pdf
25. Seidenberg, M. S., & Borkenhagen, M. C. (2020). Reading science and educational practice: Some tenets for teachers. *The Reading League, 1*(1), 7-12.