

Relevance of Neuroscience to Effective Education for Students With Reading and Other Learning Disabilities

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ABSTRACT

New directions in educational assessment and instruction are supported by recent advances in the neurosciences. Among these are early identification of potential learning problems through brief, efficient assessments of specific language skills that predict later reading outcomes; early intervention that systematically targets critical linguistic processing skills; and the necessity of stimulating all functions of a reading, writing, or computing brain. (*J Child Neurol* 2004;19:840–845).

Our understanding of language-based reading difficulties and their remediation has grown considerably in the past three decades, although conceptual and practical challenges in the identification, classification, and treatment of such children have been numerous.^{1,2} Progress in understanding reading disabilities has resulted from a comprehensive, Federally-funded research program in basic and applied sciences, including developmental psychology, cognitive psychology, cognitive neuropsychology and functional neuroimaging, pediatric neurology, genetics, and educational psychology.³ In pursuit of therapeutic models for reading disabilities, researchers have explored the mechanisms and processes of normal reading development, discovering that the role of visual and tactile-kinesthetic (manual) pathways is secondary to the roles of linguistic awareness and language proficiency.⁴ Even so, the functional and anatomic brain differences underlying reading disabilities are complex and involve multiple sensorimotor and cognitive anomalies.⁵ To teach reading, then, is to teach language processing by ear, by voice, by eye, and by hand.

What we have learned about reading disabilities and effective reading instruction is relevant to understanding a very large group of children. About 4 in 5 of the 6% nationally who are classified as learning disabled experience primary difficulty learning to read, write, and spell and can be diagnosed with language-related learning disabilities.⁶ However, about 17% of all students exhibit the

phonologic processing problems that put them at risk of reading failure,⁷ and in high-poverty environments, many more are at risk. The National Assessment of Educational Progress reports that 38% of all students nationally experience significant difficulty learning to read by fourth grade and are “below basic”; they do not read well enough to participate in grade-level classroom instruction.

The vast majority of poor readers in our schools do not exhibit IQ achievement discrepancies on psychoeducational testing and thus would not meet the diagnostic criteria for learning disabilities and special education eligibility that have been in favor for the past 30 years.⁸ Many of these children attend schools in which reading failure is the norm. Others do not demonstrate the comorbid behavioral problems that lead to special education referrals. Moreover, those who are classified do not have unique language or cognitive characteristics when they are compared with unclassified poor readers,⁹ and children’s response to instruction is predicted and accounted for by factors other than IQ, such as phonologic processing and speed of letter naming.¹⁰ Special education, as it is typically managed and delivered today, leaves classified students without significant gains or even specialized instruction¹¹ and usually does little for the larger group of unclassified students who also need research-based treatments.

Conceptions of reading disability, reading development, and reading instruction that are informed by the neurosciences could move us toward more effective treatment modalities. Such models provide a rationale for early identification of all children at risk of reading failure, for the use of assessments designed to predict long-term reading outcomes, and for instructional approaches and methods that educate all relevant brain systems. Models consistent with the findings of neuroscience can help educators reach almost all children who struggle to acquire basic academic skills. Research is far more extensive in early reading acquisition than in other areas

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of educational performance, but other types of learning disabilities and academic problems can also be addressed by research-based interventions, including instruction in language comprehension, written expression, mathematics reasoning and computation, and adaptive behavior. This article offers a conceptualization of informed treatments of the future, consistent with brain science, that are possible with better teacher preparation, stronger administrative leadership, revised policies regarding standards and the allocation of resources, and wiser use of technology.

TEACHING THE BRAIN TO READ

Preparing the Brain to Read

The neural circuitry recruited for reading develops in interaction with environmental stimulation. Studies of genetic influences on reading, for example, indicate that about half of the variance in achievement is attributable to biologic "wiring" or aptitudes and half is attributable to life experience.¹² The roots of literacy begin long before entry into formal schooling with preschool development of language. Infants until the age of 6 to 8 months are capable of processing all possible phonemes in all human languages, but before 10 months of age, they have become attuned to the phonologic systems and grammatic systems of their caregivers' language. Differentiation of phonemes in all language systems (eg, Chinese phonemes in English-exposed babies who have no experience with Chinese-speaking caregivers), which is possible for a 6-month-old child, is no longer observed in infants over age 10 months.¹³ Circuitry for language is generated and fine-tuned, probably from birth, to enable what should be the period of most rapid growth in vocabulary and syntax.

Normally developing children know the meanings of at least 5000 base words before entering first grade.¹⁴ Children who reside in low-verbal, less educated families, however, receive about one third the hours of verbal stimulation, and the verbal interactions to which they are exposed are more punitive, directive, and content deprived than are those of more educated, middle class, or professional families.¹⁵ Children who are at risk of reading failure often demonstrate striking delays in vocabulary acquisition, in addition to limited book exposure and other specific indicators of risk, such as a lack of familiarity with alphabet letters or the speech sounds they represent. To prepare preschool children for literacy, then, community-based early childhood programs could begin at about 18 months when dendrites are proliferating in the left hemisphere and expressive language is emerging. The encouragement of parents and caregivers to use nurturing tones and articulated phrases with toddlers while talking about shared experiences, even before the babies can articulate a response, is of critical importance because posterior cortical systems for language comprehension are developing faster than anterior systems for verbal production.¹⁶

Teachers and caretakers of toddlers can be taught conversational skills and awareness of their use of language during meal times, play times, activities, and book reading.¹⁷ Teaching parents and child care workers how to foster children's language development accelerates children's vocabulary acquisition and expressive language and increases their chances of reading success in first grade. Strategies such as the use of structured dialogue during

shared book reading, verbal extension of children's responses, modeling socially appropriate language, and narrating play and daily activities can significantly lower children's risk of reading disabilities. If children can be in the care of licensed preschool teachers who have learned to monitor and modulate their language patterns to promote language development, the severity and impact of language processing difficulties can be substantially reduced.

Book distribution to families through pediatric clinics, library programs, and other community contacts will continue to deserve funding from private and public sources. Children's familiarity with alphabet letter names, exposure to the language and print conventions of books, and contact with worlds experienced only through reading must be a goal of medical clinic, family literacy, and preschool programs.

Assessment to Locate Children at Risk

Assessment procedures used by teachers from preschool onward can measure critical predictors of later reading achievement.¹⁸ Children at risk can be located before they have experienced emotionally damaging struggles with basic reading skills. Among the critical indicators of later passage comprehension and reading fluency that can be measured before children actually learn to read are knowledge of letter names, the ability to identify the phonemes or speech sounds in one-syllable words (chase = /ch//α//s/), the production of the speech sounds that graphemes (letters and letter combinations that correspond to phonemes) represent, the ability to sound out simple nonsense syllables using phonic correspondences (fem, zis), and vocabulary knowledge. Moreover, such indicators are far more reliable and predictive when the measures are timed and the student's speed of response or fluency is evaluated.¹⁸

As reading is learned, the normally developing brain increasingly activates posterior areas involved in instant word recognition.¹⁹ Fluency, or speed of association of print with speech, is not only a characteristic of proficient reading, but a lack of fluency in component reading skills is one of the most enduring characteristics of poor readers.²⁰ In effect, the aim of early assessment is to determine whether students are on course to fluent reading as a result of typical classroom instruction or whether they need more intensive instruction that will normalize the brain's activation profile.²¹ Observations of the learning brain have verified the importance of automatizing the building blocks of reading, including speech sound identification and recall, letter recognition, alphabet recall, sound-symbol association, and instant word recognition.

In classrooms organized to prevent reading failure, children are screened three times per year from kindergarten onward and interventions are begun immediately for those who fail to reach a predictive benchmark score on critical indicators of later reading success. If children are "at risk," instruction can be designed to build both accuracy and fluency in the weak skills, and the response to instruction can be monitored with brief, focused assessments. Crucial to the efficacy of this endeavor, however, is the realization that reading is a multicomponent process subsumed by several functional brain networks, each recruited for a specific purpose: phonologic processing, orthographic processing, morphologic and semantic processing, and syntax and discourse processing. As the brain learns to read, the component processors must be educated to perform specific functions well so that smooth, automatic

functioning of the reading brain is possible. Well-designed lessons will include a number of components: explicit teaching about letters, speech sounds, phonics and spelling, vocabulary, and comprehension, integrated into a coherent, systematic progression.²²

Educating the Phonologic Processor

Most poor readers are slow and inaccurate at printed word recognition and are relatively weak on phonologic tasks, such as saying the individual phonemes in words, manipulating a phoneme sequence by deleting and recombining sounds, or repeating a novel sequence of syllables.²³ Children will vary, however, in the extent to which they need remedial instruction in speech sound awareness. Although the majority of poor readers demonstrate a core deficit in phonologic processing, some children are fast but inaccurate (phonologically impaired but not rate impaired), some are accurate but slow (rate impaired), and some are inaccurate and slow (with a "double deficit").²⁴ All core classroom programs should include systematic and explicit instruction in speech sound awareness,²⁵ but those children who do not respond well and who require remediation can vary in their need for explicit teaching of components such as speech sound awareness, fast word identification, vocabulary, or other reading comprehension skills.²⁶ Phonologic skill is necessary, but not sufficient, for proficient reading, and the program in use must allow the teaching emphasis to vary according to student need.

Phonologic awareness instruction should follow a developmental sequence of skill acquisition.²⁷ Methods that draw the child's attention to the oral-motor formation of speech sounds are particularly powerful. As the teacher models and instructs about the mouth movements that characterize each speech sound, children with a "tin ear for language" can learn to distinguish similar speech sounds such as /k/ and /g/ and can then segment and blend phonemes into whole words (/h/ + /ou/ + /s/). The teacher provides something that technology cannot: modeling of the mouth forms and corrective feedback for the student who must focus on the features of the sounds. Once children learn to notice the internal details of the spoken word, they are more likely to be successful at mapping print to speech.

To become fluent, the child must be helped to unitize percepts of words and recognize them instantly, and this can be accomplished even with intermediate and older poor readers given instruction that is sufficiently intense and skillful.²⁸ Intervention studies verify that students with reading disabilities require about 30 minutes daily in first grade and up to 2 hours daily in third grade and beyond to normalize their functional brain systems for reading and that conceptualization of the phoneme is the reference point for learning an alphabetic orthography. Lessons begin with sounds, link sounds to symbols, and link words to meaning.

Neuroimaging studies show not only that children and adults with reading disabilities are distinguished by underactivation of the temporoparietal areas of the left hemisphere but also that younger and older poor readers can activate right hemisphere networks that are atypical of good readers.²⁹ Thus, remediation for biologically dyslexic students is more likely to result in compensatory adjustments in functional brain systems than to eradicate neurobiologic differences. In a well-designed treatment program, planning for students is long term. It includes direct remediation of phonologic skills

while simultaneously providing compensatory tools and strategies, such as proofreading assistance for poor spelling, time extensions for slow reading, books on tape, and academic study strategies.

Educating the Orthographic Processor

Informed instruction will enable students to recognize printed words with fluency and accuracy, activating posterior cortical regions where orthographic processing takes place and where "sight word" images are stored. In the beginning stages of reading, children might know a good deal about letter sequences and print conventions through incidental exposure to them. Some children discover sound-letter correspondence from just a few encounters; many others, however, are dependent on explicit instruction that calls their attention to letter forms and letter sequences. The goal of phonics and spelling instruction is to develop the child's explicit awareness phoneme-grapheme correspondence, which, in turn, supports recognition and recall of whole words.³⁰

Each individual lesson should juxtapose exercises aimed at stimulating the essential components of a unitized, functional brain system to support word recognition. Fast communication among multiple processing networks is more likely if each is addressed separately and together. Partial approaches, for example, phonics instruction without direct and immediate application to reading and writing, have little justification within a neuroscientific approach. Rather, a variety of skills are practiced briefly and successively; children who are just learning to match sounds with symbols might search a printed page for target words in a text; practice naming upper and lower case letters with fluency; learn a grapheme for a speech sound and review known sound-symbol matches; review previously learned sight words; practice blending new printed words using phonic correspondences; and read text with learned words and patterns. Lesson design combines targeted work on component skills with the transfer and application of those skills in purposeful reading tasks.

Sound-symbol linkages, the meat of phonics instruction, are not sufficient to educate a well-functioning orthographic processor. Proficient recognition of larger units is necessary for fluent decoding of longer words that are often found in literary and informational text. Lesson design at this level incorporates words from the Latin and Greek layers of English³¹ but focuses on syllabication and morphology because memory for these larger units facilitates pronunciation of novel words encountered in text. Morphemes are the smallest meaningful parts of words and include inflectional endings (-s, -ed, -ing, -er, -est) and parts of compounds; Latin prefixes, suffixes, and roots; and Greek combining forms common in mathematical and scientific vocabulary. Morphemes are often spelled consistently; thus, a direct link can be made between visual print patterns and units of meaning (trans + port + ation; uni + cyc + le). Reading lessons should aim to include comprehensive, sustained instruction about word structure, including phonologic, orthographic, and morphologic correspondence units, throughout reading, writing, and vocabulary study from first grade to high school.

In summary, informed instruction about print will direct children's attention to the anatomy of words, both spoken and written. Mental connections between subword units (sounds, syllables, and morphemes), whole words and their semantic networks,

syntax, and the structure of the text itself are established by combining skill practice with reading worthwhile material for well-defined purposes. The principles of redundancy within and across lessons and intensive practice to achieve automaticity reflect the brain's need for repeated stimulation to establish communicative pathways. Because reading fluency enhances reading comprehension and comprehension enhances reading fluency, lessons are most effective when all components are addressed in ways that promote connections among multiple brain systems. Meaning-making, a complex enterprise, can then be facilitated by a purposeful teacher with the support of technology.

Path to Comprehension

Effective teaching of beginning reading engages attention, supports memory, and encourages self-regulation and self-correction. It is not based on rote drill but rather encourages transfer of learning to reading for meaning through teacher guidance. The teacher leads the children into the insights necessary to comprehend; she does not assume comprehension simply because the words are being read. Reading together, reading alternately, and reading silently for specific purposes are the vehicles for active questioning and discussion. The teacher's role is to preview the text with the children, provide background knowledge, engage children in connecting the topic to their own experience, and promote the active use of reading comprehension strategies. Those strategies include constructing mental images, predicting, summarizing, questioning, and clarifying and are taught by the teacher's modeling or "thinking aloud" before, during, and after reading and by queries during shared reading.³² Technology can enhance this process if text is presented electronically, and the reader can ask for clarification and background information when words, phrases, or passages are not understood.

A continual demand of comprehension is inference-making and the mental construction of idea networks or mental models of the information presented. To this end, graphic organizers—visual maps of conceptual relationships—can help children understand relationships among ideas. The task of writing a summary or retelling a narrative requires children to form mental models of overall text structure, but most children with language learning disabilities need considerable scaffolding or teacher support to approximate this challenging task, along with specific steps to follow. Skill is developed over time with extensive practice in recognizing and formulating main ideas versus supporting details, ordering ideas in hierarchical networks, using graphic organizers and outlines, and recognizing various types of paragraphs. Through coaching and demonstration, teachers can learn to question at various levels, probing the meanings of words, phrases, sentences, and discourse that language-impaired students might misunderstand and modeling proven comprehension strategies as needed.

Technologic supports can assist teachers in matching children with text at the right difficulty level on topics of interest to the student. Computer programs now exist that parse any text into phrase-size units, so that the reader avoids word-by-word reading and can pick up the phrase contours in sentence structure. Other instructional packages provide videotaped background information about informational text in science or history to familiarize students with key concepts and terms before they tackle challenging passages.

TEACHING THE BRAIN TO WRITE

Language and writing difficulties can variously originate in graphomotor, visual-spatial, attention, memory, and language formulation processes. Beginning writers must acquire automatic transcription skills to produce well-formulated compositions.³³ Instruction that applies what we know about the brain will incorporate early training in letter formation accuracy, phoneme-grapheme correspondences, spelling of high-frequency words, punctuation, and handwriting fluency so that attention and memory can be deployed in the service of language formulation, audience awareness, and discourse organization. Direct teaching of self-regulatory strategies³⁴ enhances writing length and quality in learning-disabled students in the intermediate and middle grades.

Parallel emphasis on direct teaching of component skills within a lesson that includes guided composition differs considerably from the currently dominant "writers' workshop" approach in regular classrooms, in which cumulative skill instruction is de-emphasized in favor of naturalistic, holistic, process-oriented writing activities. It is true that writing instruction for all children should be organized around real communicative goals established in social contexts so that skills are applied immediately in the service of "real writing," but skills are a necessary foundation for success. The skills part of a lesson, in which letter formation, letter naming, alphabet production, handwriting fluency, and spelling are emphasized, is brief (5 to 15 minutes, depending on students' ages). Frequent changes of activity and immediate, corrective feedback are necessary to engage short attention spans because the brain responds to novelty and to success. After working on component skills in the first part of a lesson, young children can be engaged in shared writing of a structured composition, in which teachers model and discuss the processes of planning, translation of words into print, and review of what has been written. Awareness of audience is fostered throughout writing instruction through peer and teacher conferences and publication of articles and books.

One reason for emphasizing component skills and habit formation in the beginning of the writing lesson is that practice is more likely to generalize to composition that follows immediately. It is not productive, especially for children with learning disabilities, to give negative feedback on multiple errors of spelling, grammar, and sentence structure after a composition is completed. Rather, good preparation for writing, supportive feedback during writing, the use of reference materials such as high-frequency word lists, and grading that focuses on the content and ideas are the best ways to avoid the negative emotions and aversive reactions that many students develop when writing becomes a punishing experience.

Other adaptations of instruction that help children with writing disabilities include early instruction in keyboarding and word processing, limiting handwriting instruction to either manuscript or cursive, using voice-activated text generation devices on the computer, and planning with the help of interactive software that prompts the writer to formulate key parts of the chosen genre. At the very least, a technology-based secretary can provide relief from the stress of transcription and rewriting and thus enhance motivation and enjoyment.

TEACHING THE BRAIN TO COMPUTE

Learning disabilities in mathematics are more difficult to categorize and identify than disabilities in language, reading, and writing. Less research exists about what to teach, to whom, at what point in development, and with what methods. The territory of mathematical reasoning differs from that of reading; it is more conceptual than symbolic, although each academic domain encompasses conceptual and symbolic skills. To reason mathematically, the learner develops both quantitative and logical mental models that are distributed broadly in interconnected neural networks.

Many general principles important for addressing the attention, memory, and linguistic processing problems of students with reading and writing difficulties apply to math instruction as well.³⁵ Automaticity in lower-level skills frees up the mental "desktop" for higher-level reasoning and problem solving. Thus, children need to learn their math facts, graphomotor notation of numbers, and execution of basic number operations through brief, frequent drills. Both mental arithmetic and paper-and-pencil production should be practiced. The teacher must explain the concepts and procedures using manipulative aids and concrete representations when necessary and then must orchestrate the transfer and application of skills to problem solving. Classroom discussion and collaboration during problem solving is as important to mathematical learning as it is to reading and writing.

NEUROSCIENCES AND EDUCATION: WHAT WOULD BRAIN-BASED EDUCATION MEAN FOR STUDENTS WITH LEARNING DIFFERENCES?

If schools, classrooms, instructional programs, and teacher education were to be organized according to principles supported by neuroscience, assessments of global maturity, intelligence, and readiness would be replaced by assessments of proficiency in specific neurodevelopmental domains: gross motor; fine motor; reasoning and problem solving; visual-spatial and nonverbal cognition; language processing at the levels of phonology, orthography, syntax, semantics, discourse, and pragmatics; attention; executive functions; and social-emotional development. Variations of development would not be used to delay entry into school or to retain children who are developmentally or academically delayed.³⁶ Rather, children at risk of academic failure would be identified early—at least as early as the beginning of kindergarten, if not sooner—and given the benefit of focused intervention in small groups with similar instructional needs. Educators would not wait to see what "more time" would bring because organized instruction benefits children with developmental delays more than maturation alone. Grade retention would go the way of other antiquated, unsupportable practices. Retention would be replaced by special instruction initiated for all children who scored below critical predictive benchmarks at the beginning, middle, or end of an academic year.

Children in flexible, homogeneous intervention groups of three to six children would receive focused instruction either within the classroom or outside it. Focused intervention targets the specific component skills of reading, writing, language, or math in which a student is delayed; uses validated instructional approaches; and gives ample practice so that students become accurate and

fluent in the application of component skills to academic endeavors. Additional practice occurs with the assistance of supportive technology, parent and paraprofessional tutoring, or peer-assisted learning strategies. With progress monitoring assessments given on a frequent basis, teacher teams can decide who might need even more intensive, individual work. Interventions would be delivered before expensive diagnostic testing and the development of an individual educational plan to maintain focus on the curriculum and the child's response to instruction. When problems persist or the response to instruction continues to be poor, children would be referred for a multidisciplinary evaluation to determine the nature and extent of a handicapping condition.

The context for instruction would be schools organized to invest resources preventively. The school schedule would permit teachers to work with whole groups, small groups, and individuals for sufficient amounts of time to realize meaningful gains. Teachers would be expected by administrators to use validated instructional tools for specific purposes rather than to reinvent good practices on their own. Skillful implementation of proven practices would be the first expectation for teacher evaluation. Student growth would be the primary consideration for all instructional decision making rather than performance on or preparation for arbitrary accountability measures that might have little relevance to students' instructional needs. Teachers would work with teams who shared common understandings about neurodevelopmental variations and the acquisition of reading, writing, language, and mathematical competencies. Schools would be adequately staffed to permit reasonable class size, small-group and individual instruction, and ancillary services as needed.

As this article has described, teaching is an enormously complex endeavor if it is done well. A skilled teacher who implements brain-compatible practices does many things, often simultaneously and with groups of diverse individuals. The teacher seeks actively to develop all of the functional components of complex behavioral and cognitive systems, separately and in combination. She or he plans instruction to include brief and varied routines to maintain attention and motivation. The teacher plans for transfer of skills to holistic application and ensures that sufficient practice occurs for long-term retention. The teacher often stands in for immature executive functions in learners, providing organization, scaffolding, and feedback as needed. If we could substitute technologic solutions for the human interactions required in education, society might be less concerned with the compelling issue of teacher quality and teacher preparation.

Professional organizations such as the International Dyslexia Association, the American Federation of Teachers, and the American Speech-Language-Hearing Association have called for changes in the way teachers are taught to teach reading and the way speech-language therapists function to support literacy development in schools. Teachers are not born with disciplinary knowledge³⁷ any more than physicians are born with knowledge of anatomy, yet programs of teacher preparation do not normally require teachers to learn the psychology of reading and language, the structure of language, the basics of brain-behavior relationships, or the implementation of research-based practices. When and if they do, children will be much more likely to realize the benefits of neuroscientific research. To that

end, our most urgent challenge is how to attract capable individuals into the profession of teaching, educate them for a demanding job, and support them while they are teaching. Perhaps neuroscientists can continue to inform the public not only about our marvelous insights into the brain at work but also about the sustained human effort required to realize the benefits of those discoveries.

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