Part I

What is Reading, and What are Reading Disorders? Looking to Neuroscience, Evolution, and Genetics

1 Toward a grounded synthesis of mind, brain, and education for reading disorders: an introduction to the field and this book

Kurt W. Fischer, Mary Helen Immordino-Yang, and Deborah Waber

This is a new era in the fields of education, neuroscience, and cognitive science – a time to bring together mind, brain, and education. The advent of powerful new in vivo brain imaging technologies, the power of the burgeoning discoveries in genetics, and the general excitement in society about biology make possible a new alliance relating biology, cognition, and education (*Educational Leadership*, 1998). Hidden brain and genetic processes are becoming increasingly visible (Gage, 2003; Lyon & Rumsey, 1996; Thatcher, Lyon, Rumsey, & Krasnegor, 1996), and in a few tantalizing cases, researchers and educators can even begin to observe the functional neuropsychological effects of educational interventions. It is an exciting time! This book is designed to promote the dialogue that is essential to creating the best integration of biology, cognitive science, and education.

The burgeoning new knowledge and the focus of society on biology lead to expectations that sometimes upset the balance between scientific knowledge and meaningful use in practice, raising numerous new ethical and educational issues (Battro, 2000; Bruer, 1997, 1999; *Scientific American*, 2003). The best research and the best educational practice require a two-way interaction between the scientific research and the knowledge of educators working to help children learn. Research in neuroscience and genetics, for instance, gains new significance and controversy as educators and clinicians work to translate it into practice, dealing with the strengths and weaknesses of real children learning in schools. This translation to practice should, in turn, filter back down to shape new scientific questions. In this era of translation across disciplines, no longer can neuroscience and cognitive science research remain in the ivory tower, and no longer can educational practice escape scientific scrutiny (Shonkoff & Phillips, 2000; Snow, Burns, & Griffin, 1998). Each discipline has so much to learn from the other!

Connecting mind, brain, and education

As educators, cognitive scientists, and neuroscientists, we have a responsibility to children to establish and maintain dialogue among our respective fields. To be maximally productive, this dialogue must go both ways. New information about the development and functioning of the brain awaits interpretation and judicious application in the classroom, while educational input and practical insights are essential in shaping new brain research. Indeed, the disciplines of education and neuropsychology are growing increasingly interdependent, and like the cousins from the country and the city, scientists cannot carry out good research, nor can educators carry out good practice, without interweaving these perspectives.

Society has great expectations, perhaps unrealistic ones, about the benefits of bringing biology into education. Scientists and educators are clamoring to make the connections in many ways, some of which will be productive and some of which may be disastrous (Bailey, Bruer, Symons, & Lichtman, 2001; Bruer, 1999). One important trap to be avoided is the assumption that laboratory science by itself will provide answers that can then be applied to education. A productive relation of education, biology, and cognitive science does not start in the laboratory, with direct application of scientific findings to classrooms and students.

What is required instead is a reciprocal process in which education informs biological research as much as biology informs educational research and practice (Battro, 2000; Gardner, 1983). The process should be similar to that in medicine, where medical practice informs biological research as much as biology informs medical practice. In education, reading a textbook is distant from reading a string of words in a reaction time study in a laboratory that measures brain activity with functional magnetic resonance imaging (fMRI). Results from such a different laboratory context seldom apply felicitously to the classroom. That is why so much laboratory research has failed when scientists have attempted to apply it to education.

Educational settings and tasks are essential for useful research in mind, brain, and education, just as medical settings and tasks are essential for useful research in biology and medicine. Laboratory research plays an important role in analyzing fundamental processes, but research in the settings of practice is key, and it is needed right now! Some scientists believe that it is premature to relate biology to education, that education needs to wait for scientific breakthroughs that solve the deep questions of mind and brain. We believe instead that research from education will help to shape the breakthroughs of the future by informing basic biological and cognitive research about human learning and behavior in schools and homes where children develop and learn.

How do educational interventions affect processing in the brain, and how can curricula be designed to make optimal use of developmental plasticity? Conversely, what are the educational implications of neuroscientific findings about processing of language and text, and how should these implications inform educational research and practice? To begin to address these and related questions, we must move into an era of partnership of education with neuroscience and cognitive science, in which we examine and treat educationally relevant capacities and skills from both perspectives.

In the service of promoting optimal connections of mind, brain, and education, this book is meant for neuroscientists, cognitive scientists, and educators alike. Although readers will undoubtedly be drawn initially to the chapters by their disciplinary colleagues, we urge you to delve into the chapters representing approaches other than your own. We hope that you will be inspired to many productive and innovative discussions that challenge assumptions and make connections across the fields of biology, cognitive science, and education.

Reading and learning disorder

Toward these goals, this book is conceived as a first attempt to systematically bring together the latest neuropsychological, genetic, and educational perspectives on a cognitive skill that is of central importance in both the neurosciences and education: reading. Reading is an excellent place to begin this interdisciplinary dialogue. Long traditions of cognitive neuroscientific research have attempted to pin down the component processes of reading and reading problems (Benes & Paré-Blagoev; Galaburda & Sherman; Immordino-Yang & Deacon; and Paré-Blagoev, this volume). Simultaneously, long traditions of educational research and practice have analyzed literacy instruction and interventions for teaching reading and helping students with reading difficulties (Snow *et al*., 1998; Case; and Wolf & Ashby, this volume).

Reading has been studied in far greater detail than any other area of academic competence, and reading disorders provide the most extensive, detailed, and methodologically sophisticated research literature of any learning disorder. For all these reasons and because literacy is so fundamental to our society, reading provides an ideal common focus for researchers and practitioners from diverse disciplines and perspectives to examine the interface of mind, brain, and education.

The book deals not only with reading, but it focuses especially on learning disorders. Following the long localization tradition in neuroscience, scientists and educators look to atypical as much as typical functioning to infer the component processes and developmental principles involved in reading (Geschwind, 1965; Huttenlocher, 2002; Neville & Bavelier, 1998; Pennington,

2002; Teuber & Rudel, 1962; Benes & Paré-Blagoev; Duffy; Galaburda & Sherman; Immordino-Yang & Deacon; and Paré-Blagoev, chapters in Part III, this volume; and see D. Rose, this volume, for another perspective). At the same time, understanding atypical and typical functioning requires going beyond simplistic brain–behavior correspondences to analyze how brain functioning relates to the ways real children learn and grow. When functions break down or fail to develop as expected, researchers and practitioners are afforded a unique opportunity to learn about the ways in which the brain and mind organize themselves over time, such as the ways that children functionally compensate for their neurological deficits.

The fundamental premise of this book combines biological and cognitive with educational methods and concepts to produce a new kind of disciplinarity – one that keeps a foot in each of its parent disciplines but the head in the middle. The major goals of this book are to foster meaningful interdisciplinary thinking about reading and learning disorders, and to spark discussions about how the principles derived from this thinking can be extended to other skill areas. For example, instead of considering phonological awareness independently from two perspectives – the educational perspective of reading curricula and the neurological perspective of auditory and temporal processing – we seek to bring the two together to investigate the reciprocal connections of neurological deficits with reading instruction techniques (Benes & Paré-Blagoev; Paré-Blagoev; Wolf & Ashby, this volume). Similarly, researchers and educators can explore the reciprocal connections of oral and written language comprehension with developmental changes in brain organization and cognitive capacities (Case; Fischer, Rose, & Rose; Immordino-Yang & Deacon, this volume).

Both brain and education

In working to orchestrate an innovative synthesis that furthers both education and cognitive neuroscience, the authors who contribute to this book focus on two complementary themes that run through the book, which are central to good research and practice on learning disorders. The *first theme* is the development of the relation between brain and behavior and the role of experience in shaping their functional organization. This cutting-edge issue dominates both neuroscience and education. Neuroscientists see the shaping effects of experience on brain process and organization and emphasize neural plasticity (Gage, 2003; Huttenlocher, 2002; Neville & Bavelier, 1998; Sur, Angelucci, & Sharma, 1999). Educators and developmental scientists see the behavioral manifestations in the remarkable achievements of children with major neurological problems or histories of traumatic experiences (Battro, 2000; Fischer, Ayoub, Noam, Singh, Maraganore, & Raya, 1997; Teicher, this volume).

What is the ontogeny of the sculpted functional neural networks seen in adults? Contemporary neuroscience has yet to tell what will be a fascinating story, which will ultimately be one of the most fruitful tools for applying the emergent neuroimaging technologies. How does the modularity that is characteristic of brain–behavior relations in adults develop in children, where modularity is not so evident? In children individual skills or components of skills emerge from more global developmental frameworks, within which boundaries can be initially indistinct, emerging over time.

Understanding the principles that govern localization processes in children and adults requires a concurrent educational analysis of children's evolving skill profiles in relation to the cognitive experiences created by reading instruction. This requirement underscores the essential contribution of an educational perspective to the neuropsychological study of reading disorders. While the methods of neuroimaging necessitate a focus on deficits in individual component processes, educational methods can contribute the dynamic, in situ analyses that reveal the bigger picture (Campione; Fink; Fischer, Rose, & Rose; D. Rose, this volume).

Thus the *second theme* of the book is more pragmatic – the feedback of neuroscientific and behavioral findings into educational policy and practice. At the neuropsychological level, what are learning disorders, and who has them? What neuropsychological strengths might be used to remediate weaknesses? At the educational level, what should be done for those with reading disorders in terms of assessment, instruction, and motivational techniques, and how can we characterize a successful outcome? What does a diagnosis of learning disorder mean for the broader context of a person's life?

In thinking about these questions from an interdisciplinary perspective, we come to understand reading disorder as but one manifestation of a neuropsychological profile that often can underlie difficulties in multiple domains of developmental adaptation, such as communication, social skills, and organization of goal-directed behavior (Bernstein; Case; D. Rose, this volume).

Plasticity and constraint

In the book these themes play out in the dynamic tension between plasticity and constrain in brain–behavior relations, especially in children. The structural properties of the configuration of neural networks and systems will constrain the plasticity with which children develop reading abilities and overcome reading disorders. There are no isomorphic relations between unitary structures and functions, but instead there are architectural constraints, governing the neural configuration that gives rise to behaviors and skills in a learning environment. The skills of reading, which have no evolutionary precedent to ground them firmly in neuroanatomy, are distributed within the complex networks of systems

that make up the systems for visual and oral language and comprehension (Immordino-Yang & Deacon, this volume).

A striking consistency is becoming apparent between modern functional neuroimaging studies (PET (positron emission tomography), fMRI) and the inferences drawn from years of neuropsychological observation of individuals with focal lesions, and so the architecture of language and reading networks is likely to have universal properties (Benes & Paré-Blagoev; Duffy; Paré-Blagoev, this volume; Shaywitz, Shaywitz, Fulbright, Skudlarski, Mencl, Constable *et al*., 2003). However, the greatest contribution of the functional neuroimaging studies to date is likely to be the confirmation that mental functions are associated with dynamic neural systems, not static brain regions. For example, recovering victims of brain damage, especially that incurred during infancy and childhood, demonstrate the flexibility of these networks. The interplay between this flexibility and the architectural constraints on network configuration is central to the study of reading disorders.

On a moment to moment basis, the neurological networks involved in reading are recruited in the service of several concurrent behavioral goals. Reading is thus a remarkably complex process, requiring effective timing and integration of multiple networks to be efficient. We suspect that the relatively subtle processing inefficiencies seen in children identified as learning disabled compound into debilitating reading difficulties based on the children having certain kinds of educational experiences and not others. As scientists and practitioners have widening opportunities to apply functional imaging techniques to the problem of reading disorder, the focus will evolve from the current emphasis on specific skill deficits to a dynamic analysis of the functional neural networks used in real-life learning contexts – which will facilitate analysis of the true nature of the disorder.

What are the range and limits of plasticity, and how are they mitigated by experience, such as by different kinds of reading instruction? Learning disorders entail relatively subtle individual variations in efficiency and efficacy of various cognitive functions. Not only their source but most especially their potential for change in response to interventions are uncertain. Moreover, the relative balance in emphases is likely to shift with the child's development (Bailey *et al*., 2001; Neville & Bruer, 2001; Newman, Bavelier, Corina, Jezzard, & Neville, 2001; Case; Fischer, Rose, & Rose, this volume). These issues of plasticity and constraint cut to the heart not only of our appraisal of the scientific evidence about structure–function relations, but equally importantly to our ethical beliefs about human potential and rights of the individual. To what extent should the goal of intervention for children with learning disorders be normalization of performance, and to what extent should it be helping the child to identify and prepare for a niche within which he or she can be productive and experience success? What can we reasonably expect the educational system to provide?

In the arena of these very pragmatic questions, advocates of plasticity and constraint have often collided, and there is no one obviously correct resolution of this tension.

The issues that this book addresses are not the easy ones for which answers come in black and white, but the difficult ones that reside at the boundary where plasticity and constraint meet practical educational considerations. This is one reason that we invited several neuroscientists to contribute, including some with no special expertise on learning disorders – to help frame the broad questions that need to be asked about brain, development, and learning. Some of them have contributed chapters, and some have written shorter essays to describe a relevant topic, such as brain growth cycles or the effects of traumatic experience on the brain. Effective framing of questions about brain bases of learning disorders requires dealing with questions of brain growth patterns, brain bases of language, the role of experience in shaping brain development, and genetics. After all, the ultimate goal of this interdisciplinary discussion is to tease apart the effects of experience, anatomy, and genetics on functional brain organization, to relate these principles to the case of reading, and to think about what the patterns of findings all mean for a real, developing child.

Conceptual organization of the book

In accordance with these themes and goals, the book connects mind, brain, and education throughout, although some chapters contribute more heavily to one or the other area. The book moves from the biological foundations of reading in Part I through developmental analyses of mind, brain, and education for reading and learning disorders in Part II to analyses of individual children's skill patterns in Part III. It concludes by placing reading and learning disorders in the broader context of society and lifelong development in Part IV.

The biology of reading

The first section of the book works to define the phenomena of reading disorder by placing the brain bases of reading development into a broadly biological perspective, including neuroscience, evolution, and genetics. The second and third chapters focus especially on the biological constraints of species and genes that are built into the neuropsychological capacities recruited for reading. The Immordino-Yang and Deacon chapter lays out a nested model of reading-related skills for understanding the relations between genes, brain functions, and behaviors. It also cautions against the search for one-to-one correspondences between genes and complex cognitive pursuits like reading. In the essay embedded in the chapter, Caviness describes the newly emerging study of brain volume in living brains, because differences in brain volume play a prominent

role in many neuroscientific models of learning disorders. The Galaburda and Sherman chapter makes a case for a genetic basis for dyslexia and outlines connections between genetically specified neurological abnormalities and low-level perceptual and cognitive deficits that are associated with the development of reading problems.

Taken together, these chapters present the state of the field on evolutionary and genetic research and provide tools with which to interpret new findings, but they purposely leave open the relation between top-down and bottom-up processes in the dyslexic profile – for example, the relations between attentional and phonological aspects. These relations have important implications for research on reading disorders, but sophisticated research and debate about analyzing developmental pathways and going beyond genetics alone is required to unpack the connections among higher- and lower-level processes involved in reading.

Brain, development, and reading

The second section of the book picks up the debate by working to define the various low- and high-level features of dyslexia and their relations to brain functions and developmental processes of reading and instruction. The authors provide perspectives on the history of neuroscientific and educational approaches and on important methods for analyzing the development of reading, examining existing models of reading disorder in terms of previous research and the latest findings with the new methods of cognitive neuroscience and development. The discussion centers on several key issues that cut to the core of the relation between etiology, phenotype, and development of reading disorders. These issues include reconciliation of neurological and behavioral aspects of dyslexia, analysis of variability in dyslexic profiles, and implications for the design of educational assessments and interventions.

Wolf and Ashby tackle these issues by focusing on analyses of "whole language" versus "phonological" approaches to reading instruction as well as processes of slow naming of visual stimuli in dyslexics. Case relates the study of learning disorders to the classical approaches to development and learning – empiricism, rationalism, and the sociohistorical approach – and shows how these approaches have illuminated processes behind disorders, the cognitive structures and stages involved in reading and disorders, and the cultural grounding of reading and disorders, respectively. For Fischer, Rose, and Rose, dynamic models provide a key to analyzing and supporting children's neurological and cognitive development within a common cyclic framework of brain and cognitive growth. In an essay embedded in the chapter, Thatcher describes evidence for growth cycles in neural networks in the brain.

Focusing on neuroscience, Paré-Blagoev discusses the contributions and potential of the new brain-imaging tool of fMRI in reading research. Through a

historical analysis, Benes and Paré-Blagoev present neurological explanations for some of the heterogeneity of dyslexic profiles discussed by Wolf and Ashby, and they describe the connections between the written and oral language systems of the brain. Duffy uses the electroencephalogram (EEG) to analyze cortical connections in children with learning problems, showing reduced connectivity between certain regions of the brain, a finding that may well have implications for Thatcher's and Fischer's work, as well as for work on phonological awareness. In an embedded essay, Teicher discusses the relations between childhood maltreatment and brain functioning, which demonstrate dramatically how specific experiences can reshape brain organization.

Analyzing reading and related skills

In the third section of the book, theory is brought into practice, as neuropsychologists and educators in turn present their assessments and understandings of four boys' reading and related behaviors. (Transcripts of the boys' testing sessions can be found in the Appendix.) While the chapters in the second section focus on the cognitive skills and brain processes relevant to reading, the chapters in this section work from the videos of four boys to define and debate how their skills actually present in real-life learning contexts. Bernstein provides a broad framework for neuropsychological analysis of learning differences and disorders in these and other children, underscoring the necessity of analyzing children's interactions and contexts as well as their performance on standardized measures. Brady suggests that better understanding of dyslexic children requires fuller analysis of the relations between written and oral language skills and of the fit between neuropsychological analyses and educational practices. Blachman and Torgesen both discuss a need to better understand how different neuropsychological skills manifest and interact in different educational contexts, with Blachman focusing on fluency of reading while Torgesen emphasizes the need to understand secondary deficits such as comprehension. Taylor emphasizes the relation between environmental and neurological influences, suggesting a bottom-up approach in which low-level cognitive weaknesses reveal a profile of core deficits with implications for education.

Reading skills in life

In the final section of the book, the authors emphasize long-term trajectories for reading and learning problems, broad issues of reading in schools and society, and implications for educational practice. Theory and practice from neuropsychology and education come together with a unique goal in mind – to bring life-span and societal issues to bear on the neuropsychological and educational