# Fundamentals of Developmental Cognitive Neuroscience

An exciting introduction to the scientific interface between biological studies of the brain and behavioral studies of human development. The authors trace the field from its roots in developmental psychology and neuroscience, and highlight some of the most persuasive research findings before anticipating future directions the field may take. They begin with a brief orientation of the brain, along with genetics and epigenetics, and then summarize brain development and plasticity. Later chapters detail the neurodevelopmental basis of a wide variety of human competencies, including perception, language comprehension, socioemotional development, memory systems, literacy and numeracy, and self-regulation. Suitable for advanced undergraduate and graduate courses in developmental cognition or neuroscience, this textbook covers the prenatal period through to infancy, childhood, and adolescence. It is pedagogically rich, featuring interviews with leading researchers, learning objectives, review questions, further-reading recommendations, and numerous color figures. Instructor teaching is supported by lecture slides and a test bank.

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**– H.B.**

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**– S.A.B.**

# Contents

# Preface

How do brains change from infancy through adolescence? How are they shaped by the interplay between different genotypes and environmental input? How do these brain changes manifest as changes in behavior? Our goal with this book is to introduce students to the field of Developmental Cognitive Neuroscience (DCN), the scientific interface between biological studies of the brain and behavioral studies of human development. Researchers in DCN study brain development and the corresponding cognitive, social, and emotional changes that take place beginning prenatally and continuing through childhood and adolescence. We study how a child's environment and experiences shape their developing brain.

Neuroscientific discoveries have been crucial to our understanding of psychological processes and their underlying brain basis. Nowhere is this more evident than in the field of cognitive development, a discipline focused on the perceptual and conceptual changes that emerge in concert with a brain that is growing and changing. Over the past several decades, behavioral psychologists have found new and better ways to look "under the hood" to understand the processes supporting developmental change, and neuroscientists have expanded their focus to include structural and functional mechanisms that help characterize human growth and development. Together, these efforts have had considerable impact on the way research on human development is conducted, culminating most recently in the founding of the field of DCN.

The DCN approach to research integrates measures of neural development and concomitant changes in cognitive, social, and affective processes in both typical and atypical populations. Critical to the melding of disciplines has been the application of a variety of techniques and technologies, including electrophysiology and functional neuroimaging, to the behavioral paradigms typically used in human development research. Together with insights from animal models, patient populations, and psychopharmacological and genetic assays, these approaches are providing a wider variety of data to help characterize developmental change. This book summarizes where the field currently stands, providing a much-needed integration of information from various and diverse methodological approaches, populations, and theoretical positions.

## Motivation

What do we have to offer in writing a textbook on DCN? First, we teach courses about this field at both the undergraduate and graduate levels. Second, our complementary research interests span many of the topics covered in this book, as well as the full pediatric age range from infancy through adolescence. One of us (Bortfeld) focuses on language learning from infancy through early childhood and examines experience-dependent neural plasticity in the auditory system.

The other (Bunge) has studied executive functions, various forms of memory, reasoning, environmental influences on the developing brain, and applications to education. Third, both of us use techniques that range from the behavioral to neurophysiological: Bortfeld uses looking time techniques in conjunction with functional near-infrared spectroscopy; Bunge uses cognitive measures, eye-tracking, and structural and functional magnetic resonance imaging. Thus, our collective experience as researchers covers a broad age range and many of the developmental changes therein. We also can offer our experience in teaching these concepts to students at universities with very different student populations: three different University of California campuses (Berkeley, Davis, and Merced), Stony Brook University, Texas A&M, Brown, University of Connecticut, and Stanford. Our lives and our understanding of how to teach have been meaningfully changed by our interactions with the students at these schools. The irony is not lost on us that it is perhaps we who have learned the most from interactions with those who came to us for instruction.

Why did we write this book? In teaching, we have been hard pressed to find an up-to-date textbook that approaches the complex progression of brain changes that co-occur with the emergence of human abilities in an easily tractable way. Teaching a course on DCN requires a wide range of field-specific framing, including review of anatomical detail from developmental neuroscience, behavioral methods from developmental psychology, and technological innovations from cognitive neuroscience. After many years of culling and revising reading lists to cover those topics and address those needs, we realized that we ourselves would benefit from a coherent presentation of them all together and in one place – and we thought perhaps others would as well.

## Our Approach

Our goal has been to characterize how the developing brain supports and interacts with the emergence of a diverse range of abilities. We believe that you can't begin to understand these complex capabilities without understanding the biology underlying them. Students often think of psychology in categories – cognitive, social, clinical – in large part because courses are designed to fit into specific psychological subdomains. When developmental psychology is the focus of a course, we have found that students assume biological details will not be part of the discussion. This bias is further reinforced by the superficial dichotomy of development as being influenced by nature *or* nurture, a tired framework that has stymied deeper understanding of human development. Our aim is to focus on and celebrate the interdependence of psychology and biology – of mind and brain.

For the most part, we cover research in humans from the vantage point of developmental psychology, cognitive neuroscience, and the intersection of these two fields. However, we do occasionally feature cellular and systems neuroscience research on laboratory animals that has provided important insights on a given topic. We also provide a high-level overview of genetics and epigenetics, but do not cover other areas of molecular neurobiology. As molecular, cellular, and systems neuroscience are large fields of research unto themselves, we cannot do them justice here. But in touching on these areas, we hope to spark students' curiosity about them.

To be clear, we also emphasize that understanding only the biology won't get us very far. That is, we believe that studying the biology of the brain is not an end in itself: DCN needs always to be informed and motivated by questions about actual behavior. Further, we don't

think of behavior as being divided into the biological and the cognitive/social/emotional. The complex manifestation of the latter comes about through the mechanisms and developmental trajectories of the former. These aspects of behavior are intertwined in complex, interdependent ways. Our aim here is to explore how this comes to be.

We operate on the premise that a firm grasp of cognitive and brain changes in typically developing children is essential for understanding what goes awry in neurodevelopmental disorders that affect social, motoric, linguistic, and/or cognitive development. Most importantly, we think this understanding is essential for predicting the onset of a disorder in an individual child and providing insights relevant for early detection and treatment. Because there is so much ground to cover with regards to typical development, we cannot provide comprehensive coverage of these disorders, of which there are many. However, we do highlight several disorders in association with specific topics. When we teach this course, we encourage students who are interested in clinical psychology, neuropsychology, or medicine to pick a specific disorder to investigate for a class presentation or final paper.

The field of DCN is increasingly of interest not only in the clinical realm, but also in fields as far-flung as public health, education, the law, and more. Every day, policymakers, practitioners, and the public seek out information about the developing brain, and news headlines abound. We believe that a solid foundation in DCN is important for parsing these headlines, and for making informed decisions at both the personal and societal levels. We endeavor to provide a balanced discussion of a few hot-button issues and list many others in the concluding chapter. In our classes, we invite students who are interested in the broader societal implications of DCN to pick one of the issues highlighted in Chapter 14 for a presentation or final paper.

## Organization

The book includes fourteen chapters, representing the arc of information necessary to understanding how someone progresses from a tiny cluster of cells to a sentient being. Thus, we devote the first four chapters to laying the groundwork for emerging human abilities. Chapter 2 provides an overview of the core methods used to examine development, including functional neuroimaging (fMRI/MEG), electrophysiology (EEG/ERP), functional near-infrared spectroscopy (fNIRS), and transcranial magnetic stimulation, as well as other basic neuroscience approaches based on cellular and animal models. Chapter 3 serves as a primer on genetics and epigenetics, while Chapter 4 summarizes the biological processes that underpin the emergence of a human from conception to birth and beyond, while also providing cursory orientation to the major divisions of the brain, and an introduction to the different cell types. Chapter 5 focuses on brain plasticity, providing a more nuanced examination of how nature and nurture interact continually to influence development. Chapters 6–8 provide foundational information about the emergence of basic processes – perception, attention, social awareness, and early language acquisition – that are necessary for a person to function in the world. Chapters 9–10 then focus on various forms of memory, and how we leverage memory in the service of goal-directed behavior, while Chapters 11–12 focus on the culturally constructed, educationally relevant skills of literacy and numeracy. Chapter 13 examines key drivers of behavior and the capacity for self-control.

Finally, we conclude with a chapter looking towards the future, anticipating new directions, including methods, in which the field is moving. This textbook is not intended to be a comprehensive treatment of all of DCN. For example, it does not provide extensive coverage of motor development and learning, social cognition in late childhood and adolescence, or computational research, all of which are exciting areas of research. Nonetheless, this book introduces students to DCN and a wide array of topics of active investigation in the field.

## Pedagogical Features

Our approach is to tell a story about how research on a particular subtopic arrived at where it currently is. This necessarily includes having to make difficult decisions about what to include and what to leave out to ensure the story is a coherent one. We think we have achieved this, and have added several features to help students extract the bones of each story. These include:

- Learning objectives
- Chapter summaries
- Review questions
- Further readings, including influential empirical papers and reviews

We have also included in each chapter a "Scientist Spotlight": there are excerpts from an interview with a researcher whose focus of study relates to one of the topics under discussion in the text. The purpose of these spotlights is to personalize the science by providing the origin story of leading figures in the field. Each chapter also contains a box that provides a deeper dive into the details of an issue that is relevant to the main text.

Full citations for all references mentioned in the text are provided at the end of each chapter. Key terms are bolded and defined in each chapter, with more detailed definitions provided in an accompanying glossary; additional terms are italicized and defined in the text. Finally, we provide online resources to support instructors and students, including lecture slides and a test bank of additional questions.

## Teaching with This Book

This book is intended for advanced undergraduates and early-stage graduate students who want to get into the meat of research on the brain basis for developmental change in behavior. It is ideally suited for a semester-long course (usually 14–16 weeks), but specific chapters can be selected in support of shorter course terms.

The book presupposes a high school-level biology background and an introductory psychology course. Before embarking on this journey through DCN, students should have a rough sense of the different parts of the brain and their functions. Instructors whose students have no background in neuroscience are encouraged to give an introductory lecture on gross neuroanatomy. However, students need not know neuroanatomy in depth from the outset of the course, as we introduce each brain region or network as it becomes relevant to a particular topic.

We have presented our interpretation of the story that has emerged from the body of DCN literature. We encourage instructors to add to that story with their own data points and interpretations, their own experiences, and when possible, current headlines that address the issues raised by recent findings. We include references to the original peer-reviewed scientific articles from which the data were sourced so that instructors can pursue more detailed information about any given study.

The book is designed to stand alone; a single chapter is sufficiently rich to serve as the assigned reading for one week's worth of lectures – or even two weeks, depending on the desired depth of coverage. For those wishing to take a deep dive on select topics rather than covering the entire textbook, each chapter lists empirical papers that can serve as the basis for discussion sections or student presentations. In whatever way an instructor approaches this course, we hope the excitement we experience as researchers in the field comes through in our writing.

Ultimately, our goal is for the book to help students think deeply and critically about human development, so that they can evaluate studies and formulate questions that are addressable through the methods and techniques of DCN. The mind–brain relationship has been the focus of inquiry for as long as humans have been thinking about thinking, and we happen to be passionate about understanding how the developing brain gives rise to the developing mind. Our hope is that we have adequately conveyed this passion, that it helps ignite similar excitement in students, and that it proves sufficiently intriguing to motivate many to enter this growing and continually developing field and join us in our search for the brain basis of human behavior.

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