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Book Reviews

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Book Review of "Development of Mathematical Cognition: Neural Substrates and Genetic Influences" (2016) Edited by D. B. Berch, D. C. Geary, & K. M. Koepke

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In *Development of Mathematical Cognition: Neural Substrates and Genetic Influences* (2016), Berch, Geary, and Koepke introduce readers to the most current research on mathematics cognition from a neural, genetic, and behavioral perspective. With a number of new science-based technologies and methodological innovations having been developed recently, there have been significant advances in neuroscience and genetics research related to numerical cognition over the past twenty years. Given the rapid increases in knowledge generated from these advances, there is a major need to merge neural, behavioral, and genetic approaches and knowledge. This book provides readers with a strong synthesis of the most cutting-edge findings and approaches to understanding both typical and atypical mathematics development and cognition. Throughout the 12 chapters of the book, the authors, all highly acclaimed in the field, introduce us to the most current findings and debates related to various aspects of mathematical cognition.

The book begins with a foreword by Butterworth, where he describes that, in order to address poor numeracy, we first need to understand how each child's unique "starter kit", or individualized cognitive, neural, and genetic components, construct and drive the development of numerical understanding across the lifespan from birth through adulthood (Piazza, 2010). He poses several key questions to readers such as "How do we understand numbers?", "How do these processes vary between individuals over across development?", and "How can we improve numerical understanding?". Next, the editors preface the book by introducing key theoretical debates and knowledge that have guided the past twenty years of research in mathematical cognition and development. In Chapter 1, they then describe how recent developments in neuroimaging and behavioral genetics can be used to inform our understanding of cognitive development both theoretically and empirically.

The remainder of the book is divided into two parts. Part 1 (Chapters 2-10) provide a very broad, yet rich background into the neurocognitive components and correlates that make up the foundations of core cognitive, symbolic, and nonsymbolic systems. Specifically, this section presents several studies that use neuroimaging techniques to examine the location and presence of brain activation to provide evidence supporting core cognitive structure and systems, while highlighting the importance of processes such as representation, fact retrieval, symbolic numerical processing, counting, and phonological processing on mathematics performance. In Chapter 2, Ansari addresses recent research on how the brain processes numerical symbols and emphasizes that it is still unclear how people ground symbols to connect symbolic and nonsymbolic number quantity representations in the brain. In Chapter 3, Hyde and Mou provide compelling evidence that 2 core systems of number (the approximate number system (ANS; Dehaene, 1997) and the parallel individuation system (PI; Kahneman & Treisman, 1984) are closely tied to number sense from an early age, and emphasize mechanisms and shifts in numerical processing throughout development. Chapter 4 is dedicated to exploring the transition from procedure-based to memory-based problem solving strategies. Menon focuses specifically on how brain activity changes over time, pointing out that in early development, the declarative memory system and neural activity in the medial temporal lobe are extremely active, while for adults there are patterns of neural inactivity. In Chapter 5, Berteletti and Booth emphasize the important role of finger-based strategies and representation on number processing. This chapter is particularly relevant to applied researchers and practitioners, as it highlights a growing emphasis on neural reuse (Anderson, 2014, 2016; Dehaene & Cohen, 2007) and understanding how gesture, embodied cognition, and perception play a role in mathematics learning and instruction (Alibali & Nathan, 2012; Goldstone, Marghetis, Weitnauer, Ottmar, & Landy, 2017; Ottmar & Landy, 2017). In Chapter 6, Lewis, Matthews, and Hubbard introduce a framework and provide evidence supporting a ratio processing system (RPS; Matthews & Chesney, 2015), a nonsymbolic foundation for fractions as magnitudes. In Chapters 7 and 8, Kucian and Fias provide a synthesis of studies using neuroimaging in an attempt to unpack plausible causes of deficits in children with Developmental Dyscalculia compared to more typical development. Together, they highlight the important role of a number of neurocognitive components including executive function, working memory, and anxiety on spatial attention, mathematical processing, and mental arithmetic, which ultimately impact mathematics achievement. In Chapter 9, deSmedt reviews a series of findings that identify key predictors and variability of fact retrieval, including phonological processing and symbolic numerical magnitude. His emphasis on individual and developmental differences highlights the need for longitudinal intervention studies that explore causal mechanisms as well as shifts in predictability over time. Finally, in Chapter 10, Sarkar and Jadosh present promising evidence from laboratory studies that finds that transcranial electrical stimulation may enhance various aspects of numerical cognition.

Part 2 (Chapters 11-12) summarizes the genetic components that support mathematics ability and contribute to mathematics difficulties. In Chapter 11, Petrill and Kovas provide a very thorough review of methods used in quantitative and molecular genetics, including twin and adoption studies and genome trait analysis, and they then present findings that show how genetic and environmental influences are highly important for the development of mathematical ability. In Chapter 12, Mazzocco, Quintero, Murphy, and McCloskey examine mathematical difficulties in populations of students with specific genetic disorders, including Fragile X, Turner, and 22111.2 deletion syndrome. They present findings that demonstrate enormous variability in the extent to which genetic syndromes relate to mathematical learning deficits. Although short, this section on genetic influences stresses the notion that individual differences are only partially shaped by genetic factors, leaving many questions unan-

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swered that could be explored in future interdisciplinary research in other areas, such as behavioral and cognitive science, and epigenetics.

There were several themes that were addressed and embedded throughout this book that I believe are of particular interest to researchers studying numerical cognition. First, this book reveals a need to develop and extend new measures and methodological approaches that bridge across development and between multiple fields of studies to better explain mechanisms of numerical cognition. Understanding the interconnections of neural, behavioral, and genetic influences on the development of mathematical understanding, and mapping knowledge at these different time periods is vital for moving our field forward; however, few studies in educational neuroscience, cognitive science, and math education bridge multidisciplinary approaches in a way that allows for concrete ways to measure developmental changes in the neural correlates of mathematical cognition in context. As a field, we need to work together at different levels of analysis to better expand upon the intricate interrelations of neural, biological, and cognitive processes that have been revealed in this series, with the ultimate goal of integrating these findings into usable interventions that can be scaled to more applied contexts. This view aligns well with the time-scale continuum framework proposed by Nathan and Wagner Alibali (2010). Frequently, the authors suggest that although many of the research methods, traditions, and paradigms used operate at different time scales (ranging from neural, biological, or cognitive bands and processes to organizational, developmental, or ecological levels of study), researchers at all levels should operate within a unifying framework to inform one another's research and together contribute to a unified understanding of complex behavior and learning. More emphasis on multidisciplinary work across time scales needs to be conducted to truly affect numerical, arithmetical, and algebraic thinking and learning.

A second theme that emerges is that utilizing a developmental perspective on mathematical understanding is essential for propelling our knowledge of mathematics cognition forward. Despite strong findings that suggest that the brain areas that support mathematical reasoning in adults are different than in children, many of the authors highlight that there has been very little neuroimaging work conducted with children. Although neuroimaging tools such as ERP, fMRI, and fNIRS have increasingly been used to identify key brain systems that drive mathematical processing throughout the lifespan, these methods are extremely expensive to deploy and are mostly conducted in laboratory settings with adult participants. Moving forward, there is a clear need to not only conduct more studies with young children, but also to conduct longitudinal studies that integrate both neural, behavioral, and cognitive methods to identify the critical shifts in brain and mathematical development across the lifespan.

Third, the focus on both typical and atypical development and individual differences across these chapters is also noteworthy. Understanding the type and source of impairments in students with MLD and comparing these correlations with typically developing participants provides insight into potential sources of the deficits. I also applaud the authors for having many discussions about the importance of considering culture and individual differences when interpreting findings. Too often, the implications of research findings from one population or context do not acknowledge individual differences and variability or are generalized too far. Often times, policy makers, administrators, or other stakeholders want a "one size fits all" approach, even though such approaches can often be at the detriment of students, particularly those who struggle in mathematics. The authors are very careful not to overgeneralize their findings or offer simple solutions to improving poor performance. Rather, the findings presented in this book paint a clear picture about the complexity of identifying the causes of mathematical understanding: While we know that both genetic, cognitive, and non-cognitive skills facilitate the development of mathematical understanding, very little is known about when or how these individual variables interact or influence mathematics learning across development. Mathematics performance is affected by many factors, many which are out of the child's control (socioeconomic status, genetics, parental education, prior knowledge and experiences, schooling, etc.). Each child brings a unique "starter kit", composed of both domain-specific and domain-general skills (Geary, Bailey, & Hoard, 2009; Fuchs, Geary, Fuchs, Compton, & Hamlett, 2014) which differentially interact with genetic, biological, and environmental factors.

Mathematical difficulties are increasingly prevalent in today's schools and there is increased pressure to identify strategies and interventions that can increase mathematics proficiency for all. Given that individual differences play such a strong role in mathematical development and performance, how then do we design instructional practices and interventions that can help *all* students? This brings me to a fourth theme: the need to connect basic research to practice. Although in the description, the authors claim that this book "Examines how knowledge about the developing brain can inform policy for increasing the level of mathematical proficiency in the general public", very little attention is given to this issue within the text. Although the book provides a great synthesis of the most innovative research on mathematical thinking and learning, there are many gaps with regards to dissemination that need to be filled before this work can effectively trickle down to inform policy and everyday practice (a near-impossible task for a single book!). For example, teachers, administrators, parents, and policy makers need access to the latest research and also be provided with key strategies that can be used to better serve these children. While the book does a great job of providing an overview of mathematical cognition from different perspectives, the text is highly technical and would be difficult to reach most practitioners and policy makers.

Further, given the focus on neural correlates and cognitive processes, it is unclear how practitioners and policymakers can make use of the information provided in the book to improve the state of mathematics instruction. So many students with and without MLD struggle with poor numeracy, and while this book provides a wealth of information about typical and atypical development and *why* students may struggle, there very little discussion about how we can help them. Part of this gap lies in the lack of rigorous applied studies and research-based interventions that are grounded in strong theoretical and empirical work from cognitive science, and can be used to build upon this knowledge. As a field, we need to move out of the laboratory and spend more time conducting novel research in the classroom to understand these mechanisms of learning in context. This will require that more attention (and resources!) are put into intervention design and evaluation. Rigorous randomized controlled trials and research-based intervention studies need to be conducted to better understand not only *what* works, but *how* the interventions work, and *who* they work best for. Several research teams over the past 5 years have made exciting advances in this direction by using effective cognitive science principles to create scalable classroom interventions, such as worked examples, comparison, scaffolding and feedback, explicit problem solving, embodied and perceptual learning, and using innovative technology (Barner et al., in press; Booth et al., 2017; Durkin, Star, & Rittle-Johnson, 2017; Fyfe, DeCaro, & Rittle-Johnson, 2015; Kellman, Massey, & Son, 2010; Nathan & Walkington, 2017; Ottmar & Landy, 2017). There is much more to be done in this area, but promising findings from classroom studies suggest that many of these interventions may not only improve mathematics learning at various stages of development, but test core cognitive theories in an applied context to help reveal plausible mechanisms by which various factors lead to increased mathematical understanding.

Overall, the authors provide an exceptionally thorough review of contemporary research on mathematical thinking. I would highly recommend this book for both emerging and advanced scholars in numerical cognition, as it provides a very broad, yet thorough synthesis of much of the novel and seminal work in mathematics cognition and learning. It also updates and elaborates on much of the work included in *The Handbook of Mathematical Cognition* (Campbell, 2005), making it a major contribution to the field and serving as a strong synthesis of the most cutting-edge work straddling many different scales of mathematical learning. As an interdisciplinary early career scholar who sits at the intersections of math cognition, educational technology and intervention design, and mathematics teaching and learning, this book particularly improved my understanding of how findings from neurocognitive studies could better inform each of the areas of my more applied work. My biggest takeaway from this book is this: Brain systems are complex and despite the great leaps that we have made over the past several years with regards to building knowledge, theory, and methodology about numerical cognition, many questions are left unanswered. As a discipline, we have only revealed the tip of the iceberg when it comes to understanding the neural, cognitive, and genetic underpinnings of mathematical knowledge and problem solving. Today, when political debates are high and budgets for education and novel scientific research are increasingly being slashed, it is even more vital for us to come together as a field to both produce and widely disseminate high quality interdisciplinary work that pushes our boundaries of what we know and explicitly targets what we don't know about numerical cognition using the most cutting edge tools that we have on hand. This book is a first step in the right direction towards that goal!

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