HOW THE Brain Learns Mathematics

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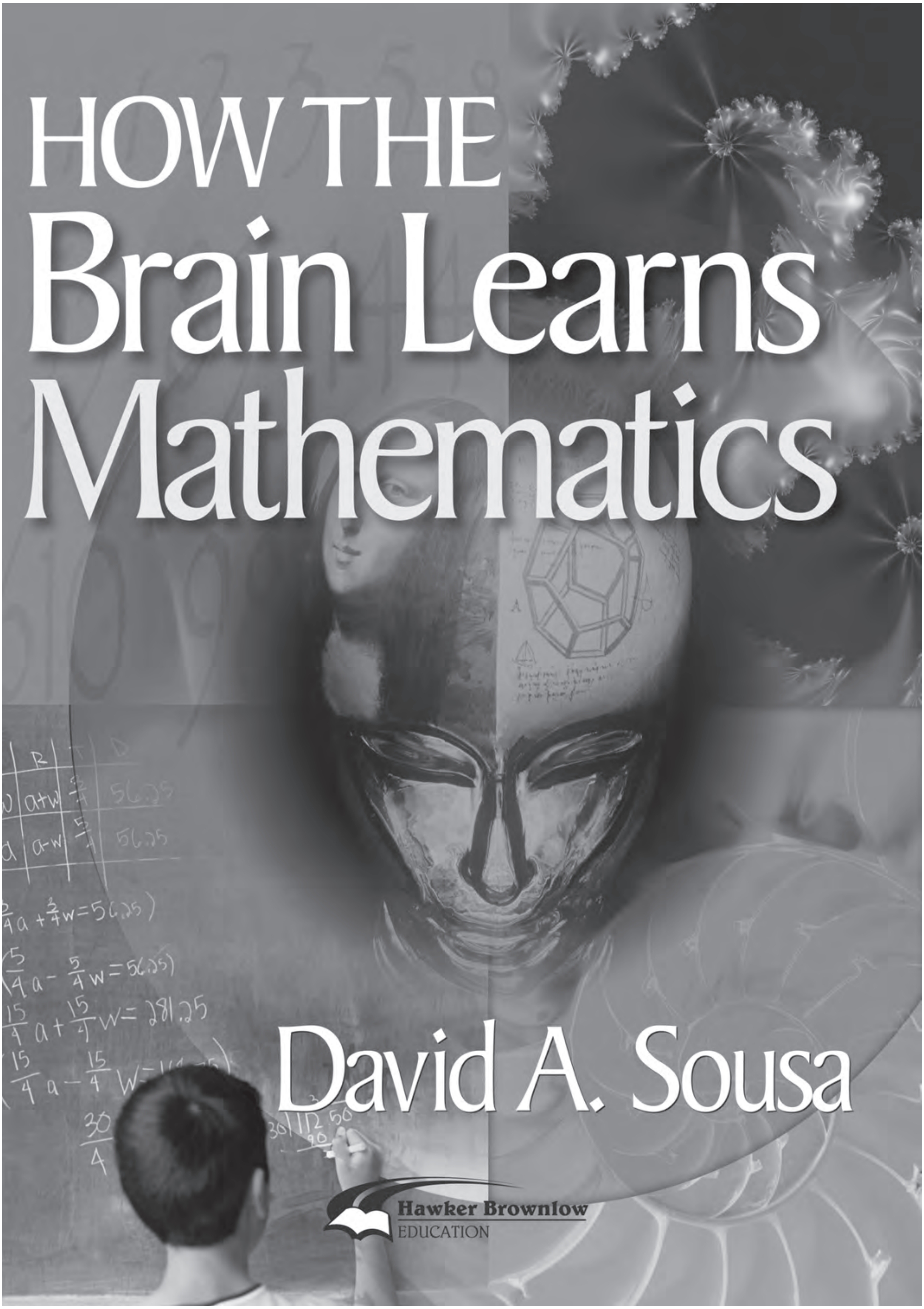

Hawker Brownlow EDUCATION

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Introduction

Numbers rule the universe.

—Pythagoras

EVERYONE CAN DO MATHEMATICS

Human beings are born with some remarkable capabilities. One is language. In just a few years after birth, toddlers are carrying on running conversations without the benefit of direct instruction. Over the next few years, their sentences become more complex, and their vocabulary grows exponentially. By the age of 10, they understand about 10,000 words and speak their native language with 95 percent accuracy.

Another innate talent is number sense—the ability to determine the number of objects in a small collection, to count, and to perform simple addition and subtraction, also without direct instruction. Yet, by the age of 10 some of these children are already saying, "I can't do math!" But you never hear them saying, "I can't do language!" Why this difference?

> *Children often say, "I can't do math!" But you never hear them say, "I can't do language!" Why this difference?*

One reason is that spoken language and number sense are survival skills; abstract mathematics is not. In elementary schools we present complicated notions and procedures to a brain that was first designed for survival in the African savanna. Human culture and society have changed a lot in the last 5,000 years, but the human brain has not. So how does the brain cope when faced with a task, such as multiplying a pair of two-digit numbers, for which it was not prepared? Thanks to modern imaging devices that can look inside the living brain, we can see which cerebral circuits are called into play when the brain tackles a task for which it has limited innate capabilities. The fact that the human brain *can* rise to this challenge is testimony to its remarkable ability to assess its environment and make calculations that can safely land humans on the moon and put a space probe around a planet hundreds of millions of miles away.

Why Is Learning Mathematics So Hard?

Succeeding in high school mathematics is still no easy feat. The results of the 2005 National Assessment of Educational Progress (NAEP) mathematics tests of 9,300 twelfth-grade students revealed that more than 39 percent fell below the proficient level in basic mathematics skills. Because the 2005 test had significant changes from earlier versions, direct comparisons to previous test results cannot be made. Nonetheless, no educator or parent can feel reassured by results showing nearly 40 percent of high school seniors performing below the minimum proficiency levels in basic mathematics. For fourth graders, the average score was three points higher, and for eighth graders the average score was one point higher in 2005 than in 2003, on a 0 to 500–point scale. These increases were barely significant (NAEP, 2007).

Explanations for this lackluster performance abound. Some say that learning mathematics is difficult because it is so abstract and requires more logical and ordered thinking. Others say that the various symbols used in mathematics make it similar to tackling a foreign language. Education critics maintain that only a few students are really developmentally incapable of handling mathematics and that the poor performance stems mainly from inadequate instruction. They cite the so-called "math wars" as hindering major progress in mathematics curriculum development similar to what the "reading wars" did to reading instruction during the 1990s.

Response From Mathematics Educators

The National Council of Teachers of Mathematics (NCTM) published the *Principles and Standards for School Mathematics* in 2000, proposing five process standards and five content standards for prekindergarten through Grade 12 mathematics instruction (NCTM, 2000). Since then, interpretation of the standards in the elementary and middle school grades became so broad that NCTM decided to refocus the curriculum at those grade levels.

In 2006, NCTM released *Curriculum Focal Points,* which identifies three important mathematical topics at each level, prekindergarten through Grade 8, described as “cohesive clusters of related knowledge, skills, and concepts,” which form the necessary foundation for understanding concepts in higher-level mathematics. The publication is intended to bring more coherence to the very diverse mathematics curricula currently in use. It provides a framework for states and districts to design more focused curricular expectations and assessments for PreK to Grade 8 mathematics curriculum development. Whether this new effort will succeed in improving student achievement in mathematics remains to be seen. In the meantime, teachers enter classrooms every day prepared to help their students feel confident enough to master mathematics principles and operations. One thing seems certain: Students who are poor in mathematics in their early years remain poor at mathematics in their later years.

ABOUT THIS BOOK

I am often asked to give specific examples of how the fruits of scientific research have made an impact on educational practice. That question is a lot easier to answer now than it was 15 years ago because recent discoveries in cognitive neuroscience have given us a deeper understanding of the brain. Thanks to brain-scanning technology we now have more knowledge about our short-term and long-term memory systems, the impact of emotions on learning, how we acquire language and motor skills, and how the brain learns to read. But it is only recently that researchers have begun to examine closely the neural mechanisms involved in processing arithmetic and mathematical operations.

Questions This Book Will Answer

This book will answer questions such as these:

- What innate number capabilities are we born with?
- How much number manipulation and basic arithmetic can young children learn without direct instruction?
- Why do Asian languages allow their native speakers to learn counting sooner and faster than English-speaking children?
- What kind of number word system could help English-speaking children learn to count easier and faster?

- Why is learning mathematics so difficult for so many students?
- What are the implications of the current research in how we learn to calculate for everyday classroom practice?
- How does the brain manage to deal with abstract mathematics concepts?
- What strategies are effective in teaching students with reading difficulties to learn mathematics?
- How can we tell if a student's difficulties in mathematics are the result of environmental factors or developmental deficits?
- What strategies should teachers of mathematics consider when planning lessons?
- What have brain imaging studies revealed about the nature of dyscalculia?
- How can elementary and secondary school classroom teachers successfully detect mathematics difficulties?
- What instructional strategies work best with students who have difficulties in mathematics?
- How can teachers use research on how the brain learns mathematics to design an instructional model for teaching PreK through Grade 12 mathematics?

Chapter Contents

Chapter 1 — Developing Number Sense. Children's ability to determine quantities begins soon after birth. This chapter examines the components of this innate number sense and how it leads to counting and basic arithmetic operations. It looks at the regions of the brain that work together and manipulate numbers and the ways in which language affects how quickly and how easily children learn to count.

Chapter 2 — Learning to Calculate. Because counting large numbers is not a survival skill, the brain must learn mathematical concepts and procedures. This chapter explores the various developmental stages that the brain must go through to understand number relationships and manipulations, such as in multiplication. It discusses why the brain views learning to multiply as an unnatural act, and it suggests some other ways to look at teaching multiplication that may be easier.

Chapter 3 — Reviewing the Elements of Learning. This chapter presents some of the recent findings from cognitive neuroscience, including discoveries about memory systems, the nature and value of practice and rehearsal, lesson timing, and the benefits of writing in mathematics classes. Gender differences as well as learning and teaching styles are also discussed.

Chapter 4 — Teaching Mathematics to the Preschool and Kindergarten Brain. Although young children have an innate number sense, certain instructional strategies can enhance those capabilities and prepare children to be more successful in learning arithmetic operations. This chapter suggests some of those strategies.

Chapter 5 — Teaching Mathematics to the Preadolescent Brain. Here we look at the development and characteristics of the preadolescent brain and how they affect the individual's emotional and rational behavior. The chapter offers suggestions on how lesson plans can be modified, from the primary grades on up to middle school, to take into account the nature of this developing brain so that more of these students will be successful in learning mathematics.

Chapter 6 — Teaching Mathematics to the Adolescent Brain. Similar to the previous chapter, we review the nature of the adolescent brain and suggest what considerations need to be made to adapt lessons to meet their needs. Included here are discussions of mathematical reasoning as well as instructional choices, such as layering the curriculum and graphic organizers, that can be very effective strategies for making mathematics relevant to today's students.

Chapter 7 — Recognizing and Addressing Mathematics Difficulties. Numerous suggestions are offered in this chapter to enable teachers to identify and help students overcome their difficulties in learning mathematics, including math anxiety. This chapter discusses the major differences between the environmental and developmental factors that contribute to mathematics difficulties. It presents some tested strategies that teachers of all grade levels can use with students who are poor at mathematics to help them understand number operations and gain a more accurate and deeper understanding of mathematical concepts.

Chapter 8 — Putting It All Together: Planning Lessons in PreK–12 Mathematics. What is mathematics? How do we use the important findings discussed in the previous chapters in daily practice? This chapter suggests ways to incorporate this research into the planning of mathematics lessons and presents a four-step instructional model for teaching PreK through Grade 12 mathematics.

Other Helpful Tools

At the end of each chapter, you will find a page called **Reflections,** an organizing tool for helping you remember important ideas, strategies, and resources you may wish to consider later.

I have included some information on the history of mathematics that I thought might be interesting and attach a human aspect to this topic. As in all my books, I have referred to the original scientific research and listed those citations whenever possible.

Look for the ✓. Most of the chapters contain suggestions for translating the research on learning mathematics into instructional practice. These suggestions are indicated with a checkmark (✓). Any time you see this symbol it means, Here is a strategy to consider!

This is not a book of activities in mathematics. Rather, this book is designed to help teachers decide which books and activities are likely to be effective in light of current research on how the brain learns mathematics.

At the back of the book is an extensive listing of Internet **Resources** that offers a wide range of activities for teachers and students at all grade levels.

This book is not meant to be a source book for mathematics activities PreK through Grade 12. Rather, it is meant to suggest instructional approaches that are compatible with what cognitive neuroscience is telling us about how the brain deals with numbers and mathematical relationships. Of course, there are some suggested activities that represent my view of how these research findings can be translated into effective classroom practice. But these are meant to suggest the *type* of activity rather than be the definitive activity. There are hundreds of books and computer programs on the market, as well as Internet resources, loaded with mathematics activities, games, and worksheets. This book is designed to help the teacher decide which of those books and activities are likely to be effective in light of current research.

The information presented here was current at the time of publication. However, as scientists continue to explore the inner workings of the brain, they will likely discover more about the cerebral mechanisms involved in learning mathematics. These discoveries should help parents and educators understand more about the nature of mathematics, mathematics difficulties, and effective mathematics instruction. Stay tuned!