Minds, Brains, and Learning

Understanding the Psychological and Educational Relevance of Neuroscientific Research

James P. Byrnes

Minds, Brains, and Learning

Understanding the Psychological and Educational Relevance of Neuroscientific Research

James P. Byrnes

THE GUILFORD PRESS
New York London

A Division of Guilford Publications, Inc.
72 Spring Street, New York, NY 10012
www.guilford.com

Printed in the United States of America

This book is printed on acid-free paper.

Last digit is print number: 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Byrnes, James P.
Minds, brains, and learning: understanding the psychological and educational relevance of neuroscientific research / James P. Byrnes.
p. cm.
Includes bibliographical references and index.
ISBN 1-57230-651-3 (hardcover)—ISBN 1-57230-652-1 (pbk.)
1. Cognitive neuroscience. 2. Neuropsychology. 3. Learning, Psychology of. I. Title.

QP360.5 .B97 2001
612.8′2—dc21 00-067750

MINDS, BRAINS, AND LEARNING

To Claire M. Byrnes, who has fostered the development of my mind, brain, and soul for so many years

About the Author

James P. Byrnes, PhD, is a Professor of Human Development in the College of Education at the University of Maryland, College Park, where he is affiliated with the Neuroscience and Cognitive Science program. He has published research in the areas of mathematics learning, decision making, language, deductive reasoning, gender differences in cognition, and ethnic differences in school achievement. He is former vice president of the Jean Piaget Society and serves on the editorial boards of a number of journals, including the *Journal of Educational Psychology*, *Child Development*, *American Educational Research Journal*, and the *Journal of Cognition and Development.*

Preface

This book began as a challenge that I posed to myself back in the fall of 1994. At that time, I was a staunch advocate of the position that there is nothing to be gained from a consideration of brain research. I am a psychologist, after all, not a biologist. And yet I was worried that I was engaging in the same sort of closed-minded thinking that has stifled scientific progress so many times over the years. In addition, some of my closest and most respected colleagues were embracing brain research with vigor. To make sure that I was not missing something important, I decided to teach a graduate course on brain research. My goal was to become familiar enough with the literature to see right through it. Much to my surprise, I ended up convincing myself that brain research could be highly relevant to the fields of education and psychology if this research is viewed in a particular light. I summarized what I learned in this process in a paper that I wrote with my colleague Nathan Fox (Byrnes & Fox, 1998). Chris Jennison at The Guilford Press read the paper and thought that it might make an excellent book if expanded considerably. The present book represents the expanded version of the original paper.

The intended audience includes three kinds of people: (1) psychologists who are highly skeptical of the relevance of brain research (or perhaps just on the fence), (2) teachers and others in the field of education who are currently being bombarded with information about the brain in teacher-oriented publications and professional development seminars, and (3) anyone else who wants to know more about the brain but is intimidated by the considerable size and complexity of the neuroscientific literature. It is my hope that my skeptical colleagues in psychology will lose some of their skepticism after reading this book. In addition, I will accomplish something important if educators who read this book learn enough to tell the difference between plausible applications of brain research and unfounded speculations. Finally, I hope that those who are merely curious about the brain will learn a great deal and be motivated to learn more. Although practicing neuroscientists are probably already familiar with much of the content of this book, I think they too could benefit from seeing how someone who is not steeped in the intellectual tradition of neuroscience views their work.

I would like to express my gratitude to the following groups of individuals. The first group includes the graduate students who participated in my course on the brain in the fall of 1994: Donetta Cochran, Vic Emerson, Mary Ann Krehbiel, Cedric Lynch, Mary Jo Primosch, Todd Riniolo, Susan Robertson, Mark Stout, Carolyn Veiga, and Maryanne Reynolds. In many ways, their enthusiasm and comments helped me to see the wisdom of learning from brain research. The second group includes colleagues who read and commented on the original Byrnes and Fox (1998) paper or on the first draft of this book: Lou Schmidt, Todd Riniolo, Mike Pressley, Keith Stanovich, Ginger Berninger, David Corina, Dave Bjorklund, Rhonda Douglas Brown, David Geary, Rich Mayer, Michael O'Boyle, Harwant Gill, Dale Schunk, Merlin Wittrock, Steve Benton, and Michael S. Meloth. I modified my original position to address many of their excellent points, but the views expressed here are my own. Next I want to thank Nathan Fox, my coauthor on the original paper, for his expert advice and for inviting me to interact with colleagues in his lab. In addition, I am grateful to Chris Jennison at The Guilford Press for encouraging me to write this book in the first place and for his excellent shepherding of the project from beginning to end. Finally, I want to thank my wife, Barbara Wasik, and children, Julia and Tommy, for supporting me with their love and patience while I wrote this book.

Contents

CHAPTER 1. Introduction 1

Arguments for and against the Relevance of Brain Research 2
Some Essential Neuroscientific Terms and Brain Structures 9
Neuroscientific Research Methods and Their Limitations 14
Summary and Preview of Remaining Chapters 22

CHAPTER 2. Brain Development 24

Further Explorations of Cytoarchitecture: Cell Types and Brain Layers 25
Seven Major Processes of Brain Development 26
Factors Affecting Brain Development 33
Conclusions and Caveats 43

CHAPTER 3. Memory 47

Human Memory as Viewed by Psychologists 48
Human Memory as Viewed by Neuroscientists 63
Conclusions and Caveats 71

CHAPTER 4. Attention 73

Psychological Perspectives on Attention 74
Neuroscientific Perspectives on Attention 83
Conclusions, Caveats, and Instructional Implications 88

CHAPTER 5. Emotion 91

Psychological Perspectives on Emotion 92
Neuroscientific Perspectives on Emotion 100
Conclusions, Caveats, and Instructional Implications 111

CHAPTER 6. Reading 115

Psychological Perspectives on Reading 115
Neuroscientific Perspectives on Reading 129
Conclusions, Caveats, and Instructional Implications 140

CHAPTER 7. Math Skills 145

Psychological and Educational Perspectives on Mathematical Abilities 146
Neuroscientific Perspectives on Math Ability 152
Conclusions, Caveats, and Instructional Implications 165

CHAPTER 8. Conclusions 169

The Educational and Psychological Relevance of Brain Research: Knowns and Unknowns 169
Evaluating Claims about the Brain 176
Final Thoughts 186

Glossary 187

References 195

Index 208

CHAPTER 1

Introduction

For many centuries, scholars from a variety of disciplines have been interested in the neural basis of thinking and learning. During the Renaissance, for example, philosophers such as René Descartes wondered how a material thing (the brain) could produce, or make contact with, an immaterial thing (the mind). Somewhat later, physicians and physiologists became intrigued by the curious deficits that sometimes occur when people experience brain injuries (Posner & Raichle, 1994). With the advent of the field of psychology in the late 1800s, a variety of new questions arose regarding the links between the brain and the mind. Even so, relatively few psychologists explored these links in a systematic way because of the common perception that brain functioning was not a matter of concern to psychologists. In many ways, this sense of the irrelevance of brain research still pervades much of psychology. However, a growing number of psychologists have apparently begun to change their opinion in recent years (Byrnes & Fox, 1998). For example, whereas only a handful of articles on cognition in the 1980s took a neuroscientific slant, a large number of cognition articles published in the 1990s focused on the neural basis of cognition and learning.

What precipitated this apparent change in perspective? Several historical trends can be identified. The first was the emergence of the field of *cognitive science* in the late 1980s. From its inception, the goal of cognitive science has been to bring together scholars from a variety of disciplines who have a mutual interest in the study of intelligence. Two key disciplines that were brought together in this collaborative enterprise were cognitive psychology and neuroscience (Posner & Raichle, 1994). The second precipitating event was the rise of the *connectionist approach* to cognition. A central premise of connectionism is that theoretical models of cognition should be based on current knowledge of brain functioning (Rumelhart, 1989). The third precipitating event was the development and increased availability of brain-imaging techniques (e.g., *positron emission tomography* and *functional magnetic resonance imaging*) that provide glimpses of brain activity as an individual engages in cognitive and emotional processing (Posner & Raichle, 1994). The fourth precipitating event was the passage of congressional resolutions that designated the 1990s as "the decade of the brain" (Wolfe & Brandt, 1998). Among other things, these resolutions prompted certain federal agencies to fund more neuroscientific endeavors.

Collectively, these four trends have created an atmosphere of increased (though certainly not universal) acceptance of the idea that neuroscientific research could provide the answers to important questions about learning and cognition. But I must underscore my use of the term "could" here. Most scholars believe that the available neuroscientific evidence is provocative and interesting, but far from conclusive. Regrettably, this fact has not stopped some authors and journalists from mischaracterizing and overinterpreting what has been found (Bruer, 1997; Byrnes & Fox, 1998). One of my goals in this book is to help the reader discriminate between the kinds of inferences that can be currently supported by neuroscientific evidence, and the kinds of inferences that cannot be so supported. In each chapter, I will critically analyze the results of certain studies using questions such as: (1) Are the findings credible and valid? and (2) Are the findings consistent across studies? By repeatedly asking such questions, the reader will learn how to avoid some of the unwarranted inferences that have appeared in the popular press in recent years. In Chapter 8, I describe and critique specific examples of these inferences using information in this book.

My goal in the present chapter is to provide an interpretive context for the chapters that follow. In the next section, I shall examine some of the arguments that have been advanced over the years regarding the irrelevance of neuroscientific evidence for psychological questions. Then, I will define and illustrate some essential neuroscientific terms (including labels of important brain structures and regions). Next, I will describe and critique the unique methodologies used by neuroscientists. Finally, I will briefly preview the content of the remaining chapters. Readers who are already familiar with the matters covered in the first three sections can skip to the final section.

ARGUMENTS FOR AND AGAINST THE RELEVANCE OF BRAIN RESEARCH

Although the number of psychologists and educators who hold positive attitudes regarding brain research has grown in recent years, the majority of individuals in these fields still see little value in this research for their own work or for the training of students. In departments of psychology or human development, for example, it is sometimes hard to find support for the idea that all students need to take courses on the physiological basis of psychological phenomena. The usual argument against offering such courses is that psychologists and educators can get along quite well without knowing anything at all about the brain. In addition to their own personal experience in this regard, faculty members who are unfamiliar with brain research can turn to influential papers written by prominent individuals to bolster their case. Before reviewing the neuroscientific evidence, then, it would seem that the first order of business is to consider the merits of some of the arguments against the relevance of brain research.

Argument 1: The Computer Analog

Several variants of the computer analogy have appeared over the years. The basic premise is that the human brain is analogous to the hardware of a computer. The mind, in contrast, is analogous to the software of a computer. As Neisser (1967, p. 6) wrote,

> The task of a psychologist trying to understand human cognition is analogous to that of a man trying to discover how a computer has been programmed. In particular, if the program seems to store and reuse information, he would like to know by what "routines" or "procedures" this is done. Given this purpose, he will not care much whether his particular computer stores information in magnetic codes or in thin films; he wants to understand the program, not the "hardware." . . . He wants to understand its utilization, not its incarnation.

In a similar way, Marr (1982) suggested that there are three levels at which some psychological process could be characterized by a theorist: the computational level, the algorithmic level, and the implementation level. The *computational* level describes the primary task to be performed by some system or individual (e.g., find the area under a curve). The *algorithmic* level describes the steps taken by a particular individual when that individual performs the task in question (e.g., uses calculus vs. measures the area with a ruler). The *implementation* level describes the mechanisms by which the algorithm is carried out in some physical system (e.g., a brain or a computer). Marr argued that when researchers are trying to create a computer simulation of some cognitive process (e.g., vision), they can temporarily ignore implementation issues when they are working on issues at the computational and algorithmic levels. In other words, they need not worry about such things as whether the program will run on a Macintosh or an IBM when they are considering what the task will be and what algorithm will be used to accomplish the task. Many scholars have used Marr's account to argue that psychologists normally operate at the computational and algorithmic levels when they construct theories of mental events. As such, they, too, do not have to be concerned about implementation issues (i.e., how the brain manages to carry out some cognitive process).

The computer analogy is part of a larger and very influential paradigm known as the *computational theory of mind* (Block, 1990; Pylyshyn, 1989). The basic claim of the computational theory is that "the mind is the program of the brain and that the mechanisms of the mind involve the same sorts of computations over representations that occur in computers" (Block, 1990, p. 247). For my present purposes, the details of this claim are less important than the ultimate realization that

> the computer model of the mind is profoundly *unbiological*. We are beings who have a useful and interesting biological level of description, but the computer model aims for a level of description of the mind that abstracts away from the biological realizations of cognitive structures. . . . Of course, this is not to say that the computer model is in anyway incompatible with a biological approach. Indeed, cooperation between the biological and computational approaches is vital to *discovering* the program of the brain. . . . Nonetheless, the computer model of mind has a built-in antibiological bias in the following sense. If the computer model is right, we should be able to create intelligent systems in our image. . . . It is an open empirical question whether or not the computer model of mind is correct. Only if it is *not* correct could it be said that psychology, the science of mind, is a biological science. (Block, 1990, p. 261)

In effect, then, psychologists and educators could easily appeal to the still-dominant computational theory of mind to defend their claim that neuroscientific questions are somewhat irrelevant. For example, an educator could say, "I am only interested in the strategies children use to solve math problems [i.e., the algorithmic level]. I am not interested in the biological mechanisms responsible for their brains' ability to envision and carry out these strategies [i.e., the implementation level]. How would knowing the latter make me a better teacher?"

This is obviously a good question and one that is based on a compelling line of argumentation (that I have only touched on here). The key to finding flaws in this line of argumentation is to consider the ways in which the computer analogy of mind is either misleading or incorrect.

Rumelhart (1989, p. 134) adopts the former approach and suggests that Marr's three-levels account is

> true for computers because they are essentially the same. Whether we make them out of vacuum tubes or transistors, and whether we use an IBM or an Apple computer, we are using computers of the same general design. When we look at an essentially different architecture [e.g., the brain], we see that the architecture makes a great deal of difference. It is the architecture which determines which kinds of algorithms are most easily carried out on the machine in question. It is the architecture of the machine that determines the essential nature of the program itself. It is thus reasonable that we should begin by asking what we know about the architecture of the brain and how it might shape the algorithms underlying biological intelligence and human mental life.

To extend Rumelhart's argument somewhat, consider the following. Would an aviation expert ignore the object that is flying when he or she is providing a theoretical account of this object's flight (Iran-Nejad, Hidi, & Wittrock, 1992)? A little reflection shows that the answer is clearly no. An explanation of how a bird manages to fly would differ in important respects from an explanation of how an airplane flies. Similarly, would a physicist ignore the molecular structure of particular magnets when he or she is explaining the functioning of magnets? Again, the answer would be no. Some objects are only magnetic when electricity is running through them, others can be permanently magnetized, while still others can only be temporarily magnetized. Hence, the thing that is flying or attracting metal is clearly important. If we failed to think about the object involved, we would never really develop a useful or accurate theory of flight or of magnetism. In the same way, if psychology is a science comparable to physics or chemistry, it should definitely matter to practitioners of this science whether a brain or a computer is carrying out an algorithm.

Searle (1992) argues that the computer analogy is not only misleading, it is also incorrect and incoherent. As I noted above, a basic assumption of this analogy is that a particular algorithm can be carried out on a potentially infinite number of physical mechanisms. For example, one could add on one's fingers, on a calculator, on an abacus, and so on. Searle argues that "the multiple realizability of computationally equivalent processes in different physical media is not just a sign that the processes are abstract, but that they are not intrinsic to the system at all. They depend on an interpretation from the outside" (p. 209). In other words, people assign meaning to the inputs and the outputs of things such as calculators. Numbers and mathematical operations are not intrinsic to calculators because we could make the same transistor states and key presses correspond to words and other things, not just to numbers. But if the brain causes cognition (as most people think it does), then cognition *is* an intrinsic property of the brain in the way computation seems not to be. As such, cognition is more like features of the world such as the molecular structure of substances (e.g., H_2O for water) or the shape and color of common objects (e.g., the roundness of an orange). Computation, in contrast, is more like features such as "nice day for a picnic" which require an observer to assign this property to the world (Searle, 1992). Take away the observer and the latter feature would not exist.

Argument 2: The Explanatory Vocabulary Account

Scientific theories are said to "carve nature at its joints" (Pylyshyn, 1984; Kosslyn & Koenig, 1992). Individual sciences, however, carve nature at different levels of analysis and explain different types of phenomena. To illustrate, imagine a situation in which a physicist, a biologist, and a psychologist all attend the same baseball game. During a particular inning, the pitcher throws a curve ball and strikes a batter out. If someone were to ask "Why did he throw a curve ball?," the psychologist could provide a satisfactory answer to this question by making use of mainstream psychological constructs such as knowledge and desires (e.g., "He *wanted* to strike him out and *knew* that the batter was not very good at hitting curve balls"). In contrast, neither the physicist nor the biologist could provide a satisfactory answer using mainstream constructs from physics or biology. For example, the physicist would have to say something like "Air currents operating over the laces caused the ball to curve . . . ," while the biologist would have to say something like "Neural impulses traveled down his arm, causing a contraction in his right arm muscle. . . . " Note that such answers tell us why the ball curves and how a human body can move to produce a curve ball, but they do not directly answer the question asked above. In a sense, then, there are certain questions that only a psychological theorist could answer in the manner intended. As such, anyone who tried to answer psychological questions with a biological (or even quasi-biological) vocabulary would end up providing an inadequate answer (Pylyshyn, 1984; Putnam, 1973).

Although this account seems reasonable, note that it assumes that someone would try to provide a neurological answer to a psychological question. Neuroscience does not provide answers to questions such as

"Why did he throw a curve ball?," but rather to questions that *follow up* on psychological answers. For example, after learning about Baddeley's (1999) claim that there are two kinds of working memory systems, spatial and verbal, a neuroscientist might ask, "I wonder if there are regions of the brain that correspond to these two types of memory?" Similarly, after learning that gifted children seem to solve math problems more proficiently than nongifted children, a neuroscientifically oriented researcher might wonder whether math knowledge is represented differently in the brains of gifted and nongifted students. Thus, neuroscientific questions extend well beyond questions having to do with the brain's ability to carry out some function. To suggest that neuroscience can only answer such "how" questions is misleading.

Note further that the explanatory vocabulary account was originally proposed as a argument against reductionism (not against the utility of asking neuroscientific questions). Reductionist philosophers argue that the laws of so-called higher level sciences such as psychology and sociology are reducible to the lower level sciences such as biology, chemistry, and physics (Putnam, 1973). As such, reductionists argue that the only reason we use psychological vocabulary terms is because we have not quite figured out the biology. By showing that the psychological explanatory vocabulary is indispensable, the anti-reductionists show that psychology is not reducible to biology.

At this point, it should be noted that there is an important difference between (1) being interested in the implications of neuroscientific research for psychological theories and (2) wanting to replace a vague psychological terminology with a more precise biological vocabulary. Whereas the latter approach is reductionistic, the former approach is not because the focus of interest is the interface between two sciences that continue to maintain their separate existences and integrity. As will become clear, I adopt and promote the interface approach in this book. In essence, then, there is no basis to the claim that an interest in the brain necessarily makes one reductionistic.

Argument 3: Too Little Is Known about the Brain

Some scholars have suggested that neuroscientific research is not terribly informative at present because the data are still somewhat tentative and basic. If this claim is true, then psychologists have two choices: they can either wait until more neuroscientific information comes in before constructing a model of cognition, or they can forge ahead on their own without considering the biological plausibility of their models. Several prominent individuals have argued that the latter course of action is the