Learning and Memory

From Brain to Behavior

THIRD EDITION

Mark A. Gluck • Eduardo Mercado • Catherine E. Myers

Learning and Memory

From Brain to Behavior

THIRD EDITION

Mark A. Gluck
Rutgers University–Newark

Eduardo Mercado
University at Buffalo, The State University of New York

Catherine E. Myers
Department of Veterans Affairs, VA New Jersey Health Care System,
and Rutgers University–New Jersey Medical School

worth publishers
Macmillan Learning
New York

Publisher, Psychology and Sociology: Rachel Losh
Senior Acquisitions Editor: Daniel DeBonis
Development Editor: Moira Lerner Nelson
Assistant Editor: Katie Pachnos
Executive Marketing Manager: Katherine Nurre
Executive Media Editor: Rachel Comerford
Assistant Media Editor: Nicole Padinha
Director, Content Management Enhancement: Tracey Kuehn
Managing Editor, Sciences and Social Sciences: Lisa Kinne
Project Editor: Kayci Wyatt
Media Producer: Elizabeth Dougherty
Senior Photo Editor: Christine Buese
Photo Researcher: Jacqui Wong
Senior Production Supervisor: Paul Rohloff
Director of Design, Content Management: Diana Blume
Design Manager: Vicki Tomaselli
Cover and Interior Design: Kevin Kall
Art Manager: Matthew McAdams
Illustrations: Todd Buck, Eli Ensor, Matthew Holt, Christy Krames, and Hans Neuhart
Composition: MPS North America, LLC.
Printing and Binding: Donnelly
Cover Photo:
Man Ray Contemplating the Bust of Man Ray, 1978
William Wegman
Silver Gelatin Print
8 × 8 Inches

Library of Congress Control Number: 2015960602

ISBN-13: 978-1-4641-0593-7
ISBN-10: 1-4641-0593-6

Printed in the United States of America

First printing

Worth Publishers
One New York Plaza, Suite 4500
New York, New York 10004-1562
www.macmillanlearning.com

To my nifty nieces, Mandy (19) and Kamila (16):
Over the course of three editions you have grown—both in real life
and as the fictional characters herein—from darling little girls
to delightful young ladies.

M. A. G.

To my son, Iam.

E. M. III

To the memory of dear friends lost to cancer this year,
and in honor of the brave friends who continue their battles.
You teach me the true meaning of courage and commitment.

C. E. M.

ABOUT THE AUTHORS

Mark A. Gluck is a Professor of Neuroscience at Rutgers University–Newark, Director of the Memory Disorders Project at Rutgers University, and Co-Director of the African-American Brain Health Initiative. His research focuses on the cognitive, computational, and neural bases of learning and memory, and the consequences of memory loss due to aging, trauma, and disease. He is co-author of *Gateway to Memory: An Introduction to Neural Network Modeling of the Hippocampus and Learning* (MIT Press, 2001) and co-editor of three other books. In 1996, he was awarded an NSF Presidential Early Career Award for Scientists and Engineers by President Bill Clinton. That same year, he received the American Psychological Association (APA) Distinguish Scientific Award for Early Career Contribution to Psychology. More on his research and career at www.gluck.edu.

Eduardo Mercado is a Professor of Psychology and of Ecology, Evolution, and Behavior at the University at Buffalo, The State University of New York. His research focuses on how different brain systems interact to develop representations of experienced events, and how these representations can be changed over time through training, especially as these processes relate to neural and cognitive plasticity. He is a Fellow of the Center for Advanced Studies in the Behavioral Sciences at Stanford, and an investigator in the multi-institutional Temporal Dynamics of Learning Center.

Catherine E. Myers is a Research Scientist with the Department of Veterans Affairs, New Jersey Health Care System, and a Professor in the Department of Pharmacology, Physiology, and Neuroscience at the New Jersey Medical School, Rutgers University. Her research includes both computational neuroscience and experimental psychology, and focuses on human learning and memory, especially in clinical disorders such as amnesia and post-traumatic stress disorder (PTSD). She is co-author of *Gateway to Memory: An Introduction to Neural Network Modeling of the Hippocampus and Learning* (MIT Press, 2001) and author of *Delay Learning in Artificial Neural Networks* (Chapman and Hall, 1992).

BRIEF CONTENTS

this page left intentionally blank

CONTENTS

PREFACE

This is the third edition of *Learning and Memory: From Brain to Behavior*, following the success of our first two editions published in 2008 and 2014. The new edition continues our approach of presenting a comprehensive, accessible, and engaging introduction to the scientific study of learning and memory. The modular table of contents unique to this textbook allows the course to be taught in any of at least four different ways: (1) Learning first, then Memory; (2) Memory first, then Learning; (3) Memory only; or (4) Learning only. As described in greater detail below, the chapters are grouped into four modules: an Introductory Module, a Learning Module, a Memory Module, and an Integrative Topics Module. Adding to the convenience of this organizational scheme, the topics within all the core chapters are grouped into the same three major subsections: Behavioral Processes, Brain Substrates, and Clinical Perspectives. This innovative organization has been acclaimed by users of the second edition. It provides a highly flexible curriculum suited to the many different ways that teachers prefer to teach this material.

Notable changes in our new edition include:

- *Increased use of real-world examples*, concrete applications, and clinically relevant perspectives.
- *Expansion of integrated and end-of-chapter pedagogy* to help students assess their own progress and understanding. By integrating pedagogy into the body of each chapter, we provide students with immediate practice and feedback, help them organize and prioritize information, and generally assist them in using the book more effectively. A new end-of-chapter quiz tests recall of key information after reading of the chapter is completed.
- *Stronger and more extensive teacher support* through supplemental materials and a complete, ready-to-use package of PowerPoint slides for each section of each chapter.
- *Even more integration of topics across chapters*, highlighting connections between themes and concepts that arise repeatedly in different parts of the book.

In addition to the flexible modular structure and solid pedagogy, *Learning and Memory: From Brain to Behavior*, Third Edition, is notable among textbooks in its field for its strong neuroscience focus, integrative coverage of animal learning and human memory, engaging writing style, extensive four-color art program, and emphasis on showing students how basic research has direct implications for everyday life and clinical practice.

Flexible Modular Table of Contents

There are at least four different ways in which teachers can choose to teach this material:

1. **Learning only.** Focusing on animal conditioning and behaviorist approaches; teachers may or may not include neuroscience perspectives.
2. **Memory only.** Focusing primarily on human memory and cognition; teachers include varying degrees of cognitive neuroscience perspectives.
3. **Learning, then memory.** Starting with basic learning phenomena such as habituation, sensitization, and associative conditioning—phenomena most extensively studied in animals—and progressing to the more complex facets of human memory. Neuroscience coverage, when included, begins with the most elemental building blocks of neurons and circuits and works up to the larger anatomical perspectives required by the human memory studies.

4. **Memory, then learning.** Here, teachers start with the most engaging and familiar material on human memory, including its many failings and idiosyncrasies, topics that students usually find especially relevant and appealing. As the course progresses, teachers present material on how human memory is built up from basic processes that can be studied in greater precision in animal models. Neuroscience coverage begins with the most accessible and easily understood big-picture view of anatomical regions and their functional relevance and then works toward presenting the greater detail and neuronal focus of studies that can be done invasively in animal preparations, especially studies of conditioning and other forms of associative learning.

Does the field really need four different types of textbooks to support the diversity of approaches to teaching this material? In the past, the answer was, unfortunately, "yes": every textbook followed one of these approaches, and instructors had to find the book whose orientation, organization, and coverage best matched their own plans for the course. However, with *Learning and Memory: From Brain to Behavior*, Third Edition, there is now available a single textbook that is sufficiently modular in its overall structure and in the execution of individual chapters to accommodate all four approaches to teaching this material.

How can one textbook suit every teaching approach?

To accomplish this feat, we have divided the book into four multichapter modules:

- The **Introductory Module** is the natural starting point for all courses; teachers can assign either or both of two introductory chapters, one a conceptual and historical overview of the study of psychology and behavior, the other an introduction to the neuroscience of learning and memory.
- The heart of the book consists of two "parallel" modules, the **Learning Module** and the **Memory Module**. These can be covered singly (for those teachers who wish to teach only learning or only memory) or in either order, allowing for a learning-then-memory syllabus or a memory-then-learning syllabus. Each of these modules is a self-contained collection of chapters, neither of which assumes that the student has read the other module. The Learning Module has four chapters, covering basic exposure-driven learning mechanisms; classical conditioning; operant conditioning; and, finally, generalization, discrimination, and similarity. The Memory Module has three chapters, covering episodic and semantic memory, skill memory, and working memory and cognitive control.
- The final module of the book, the **Integrative Topics Module**, consists of three optional stand-alone chapters (so that any subset of the three can be assigned), covering emotional learning and memory, social learning and memory, and lifespan changes in learning and memory, from prenatal development to old age.

Given the book's flexible, modifiable, and modular structure, we believe we have written the first textbook for every instructor in the fields of learning and/or memory, reflecting and respecting the heterogeneity and diversity of the many different approaches to teaching this material.

Can this book be used for a Principles of Learning and Behavior course?

Indeed it can. Although more and more colleges are offering courses that integrate animal learning and human memory and include ever-increasing amounts

of neuroscience, there are still a large number of teachers who prefer to focus primarily on animal learning and conditioning, along with modest coverage of related studies of human associative learning, all presented primarily from a behavioral perspective.

For such a course, we recommend starting with Chapter 1, "The Psychology of Learning and Memory," then covering the four chapters of the Learning Module (Chapters 3 through 6), and concluding with Chapter 10, "Emotional Influences on Learning and Memory," which examines key topics in fear conditioning. Together these six chapters present a lucid, compelling, accessible, and engaging introduction to the principles of learning and behavior. We recognize, of course, that six chapters cannot provide as much detailed coverage as a single-approach textbook with 12 or more chapters on these topics. For this reason, we have included extensive additional materials on learning and behavior in the teacher's supplemental materials for the Learning Module chapters. These materials provide the additional flexibility and content to support spending two weeks, rather than one week, on each of the four Learning Module chapters. This combination of textbook and supplemental materials serves well the teacher who wishes to spend 10 or more weeks on principles of learning and behavior with a primary focus on animal learning and conditioning.

Specialized learning and behavior textbooks are often dry and unappealing to most students. By adopting our book, instructors who prefer the learning and behavior approach will be providing their students with a text that has a uniquely engaging writing style, helpful integrated pedagogy, extensive four-color art, and a strong focus on showing students how basic research has direct implications for everyday life and clinical practice.

Neuroscience Focus

Neuroscience has altered the landscape for behavioral research, shifting priorities and changing our ideas about the brain mechanisms of behavior. *Learning and Memory: From Brain to Behavior* integrates neuroscience research into each chapter, emphasizing how new findings from neuroscience have allowed psychologists to consider the functional and physiological mechanisms that underlie the behavioral processes of learning and memory. Chapter 2, "The Neuroscience of Learning and Memory," offers an accessible introduction to neuroscience for students unfamiliar with the basics of brain structure and function. Thereafter, the "Brain Substrates" section of each of the book's core chapters (3 through 12) presents the neuroscience perspectives relevant to the chapter topic, to be assigned or not as the teacher wishes (omitted by those teachers who prefer to present only a behavioral perspective).

Integrated Presentation of Learning and Memory Research across Species

The field of learning and memory has undergone enormous changes over the last decade, primarily as a result of new developments in neuroscience. As we have gained a greater understanding of the neurobiological bases of behavior, the strict conceptual boundary between the biological approach and the psychological approach to the study of learning and memory has begun to disappear. Moreover, after several decades during which learning by humans was studied

and described in one field of science and learning by animals was studied in another, the discovery of basic biological mechanisms common to all species has launched a unified approach to behavioral studies. Although our book takes a modular approach to teaching this course, distinguishing the chapters that focus primarily on learning from those that focus primarily on memory, the story that emerges from covering both sets of chapters is, we believe, the strongest and most up-to-date representation of the field as a whole.

Clinical Perspectives

In addition to examining and explaining new research in learning and memory, *Learning and Memory: From Brain to Behavior*, Third Edition, traces how these findings have spurred the development of new diagnoses and treatments for a variety of neurological and psychiatric disorders. Recent advances in neuroscience have produced dramatic changes in clinical practices over the last decade, greatly affecting how neurologists, psychiatrists, clinical psychologists, nurses, and rehabilitation specialists diagnose and treat the clinical disorders of learning and memory. Alzheimer's disease, autism, schizophrenia, Parkinson's disease, dyslexia, anxiety disorders, ADHD, and stroke are just a few of the disorders for which new treatment options have been developed as a result of basic behavioral and cognitive neuroscience studies of learning and memory. To reflect this broader impact of the field of learning and memory, each of the core chapters (Chapters 3 through 12) includes a "Clinical Perspectives" section that shows how knowledge of behavioral processes and brain substrates is being applied to understand clinical disorders that lead to disruptions of learning and memory. These sections are one way in which the book emphasizes the influence of learning and memory research in the real world and shows how neuropsychological research informs our understanding of memory mechanisms.

Student Friendliness

- **No Prerequisites.** We understand that students may come to this course from different backgrounds, even different disciplines, so we do not assume any previous level of familiarity with basic psychology or neuroscience concepts. The first two chapters of the text offer a complete overview of the field of the psychology of learning and memory and the neuroscience foundations of behavior. Later chapters explain all new concepts clearly with emphasis on real-life examples and teaching-oriented illustrations.
- **Engaging Narrative.** Our aim has been to create a lively, clear, and example-rich narrative, a colorful conversation between authors and readers that communicates our vision of an exciting field in transition and captures the interest of students by igniting their curiosity.
- **Full-Color Art Program.** The full-color art program consists of original anatomical art, state-of-the-art brain scans, and color-coded figures to help students visualize the processes involved in learning and memory. Photos offer a link to the real world, as well as a look back in time; cartoons provide occasional comical commentary (and often additional insights) alongside the main narrative.
- **Real-World Implications.** *Learning and Memory: From Brain to Behavior* is noted for a strong focus on applications and on the relevance of learning and memory concepts to everyday life. In addition to the "Clinical Perspectives" section at the end of every core chapter, we have included throughout each

chapter many concrete, real-world examples of learning and memory that help students grasp the implications of what they are studying and its relevance in their own lives.

- **Consistent Organization.** The integration of both neuroscience and relevant clinical issues throughout the text is made more accessible to the student by the book's consistent tripartite division of each chapter into the sections "Behavioral Processes," "Brain Substrates," and "Clinical Perspectives." As described above, this also allows teachers to selectively omit the discussions of brain substrates or clinical perspectives from some or all of the reading assignments if that better suits a teacher's syllabus. In addition, each chapter ends with a "Synthesis" discussion that recaps and integrates selected key issues in the chapter.

Extensive Pedagogy

- **Test Your Knowledge** exercises introduced at intervals throughout each chapter give students the opportunity to check their comprehension and retention of more challenging topics immediately after having read about them. Suggested answers are provided.
- **Learning and Memory in Everyday Life** boxes in each chapter illustrate the practical implications of research, especially those that are relevant and interesting to undergraduate students.
- **Interim Summaries** follow each chapter subsection to help students review major concepts presented in the pages they have just finished reading.
- **Quiz Yourself** fill-in-the blank exercises at the end of each chapter test recall of key topics and concepts. Page numbers where the information was presented are provided with each exercise, and answers are given at the end of the book.
- **Concept Checks** at the end of each chapter ask critical-thinking questions that require an understanding and synthesis of the key material in the chapter. These exercises ask students to apply the knowledge they've gained to a real-life situation. Suggested answers are provided at the end of the book.
- **Key Terms** are defined in the text margins for emphasis and easy reference and then are listed at the end of each chapter, with page numbers, to help students review chapter terminology. All key terms with their definitions are also included in an end-of-text glossary.

Media and Supplements

All of the supplementary materials can be downloaded from the Macmillan Learning catalog site at www.macmillanlearning.com.

Book-Specific Lecture and Art PowerPoint Slides

To ease your transition to *Learning and Memory*, a prepared set of lecture and art slides, in easy-to-adopt PowerPoint format, is available to download from the catalog site. The book-specific PowerPoint Lecture Slides include a variety of in-class activities and are authored by Robert Calin-Jageman of Dominican University and Chrysalis Wright of the University of Central Florida.

Instructor's Resource Manual

The Instructor's Resource Manual, authored by Chrysalis Wright of the University of Central Florida, includes extensive chapter-by-chapter suggestions for in-class presentations, projects, and assignments, as well as tips for

integrating multimedia into your course. It also provides more comprehensive material on animal learning for instructors who allocate more of their courses to the classic studies of animal learning.

Diploma Computerized Test Bank

The Test Bank, written by Anjolii Diaz of Ball State University, features approximately 100 questions per chapter as well as an assortment of short-answer and essay questions. The Diploma software allows instructors to add an unlimited number of questions, edit questions, format a test, scramble questions, and include pictures, equations, or multimedia links. With the accompanying Gradebook, instructors can record students' grades throughout a course, sort student records and view detailed analyses of test items, curve tests, generate reports, add weights to grades, and more.

Course Management Aids

As a service for adopters who use course management systems, the various resources for this textbook are available in the appropriate format to be downloaded into their campus CMS. The files can be customized to fit specific course needs or they can be used as is. Course outlines, pre-built quizzes, links, and activities are included, eliminating hours of work for instructors.

Acknowledgments, to Our Colleagues

This book has benefited from the wisdom of expert reviewers and instructors from laboratories and classrooms around the country. From the earliest stages of the development process, we solicited feedback and advice from the leading voices in the field of learning and memory to ensure that the book expresses the most current and accurate understanding of the topics in each chapter. Over the course of the book's development, we have relied on these experts' criticism, corrections, encouragement, and thoughtful contributions. We thank them for lending us their insight, giving us their time, and above all for sharing in our commitment to creating a new textbook and a new curriculum that reflect a contemporary perspective on the field.

Michael Todd Allen
University of Northern Colorado

John Anderson
Carnegie Mellon University

Hal Arkes
Ohio State University

Larissa Arnold
Iowa State University

Amy Arnsten
Yale University

Ed Awh
University of Oregon

Padmini Banerjee
Delaware State University

Deanna Barch
Washington University, St. Louis

Carol Barnes
University of Arizona

Mark Basham
Metropolitan State College of Denver

Mark Baxter
Oxford University

Kevin Beck
VA New Jersey Health Care System and New Jersey Medical School

Matthew Bell
Santa Clara University

April Benasich
Rutgers University–Newark

Anjan Bhattacharyya
New Jersey City University

Evelyn Blanch-Payne
Georgia Gwinnett College

Monica Bolton
University of Nevada, Las Vegas

Gordon Bower
Stanford University

Jennifer Breneiser
Valdosta State University

György Buzsáki
New York University

John Byrnes
University of Massachusetts

Larry Cahill
University of California, Irvine

Robert Calin-Jageman
Dominican University

Thomas Carew
University of California, Irvine

Leyre Castro Ruiz
The University of Iowa

KinHo Chan
Hartwick College

Henry Chase
Cambridge University

Arlo Clark-Foos
University of Michigan-Dearborn

Jennifer Coleman
Western New Mexico University

Roshan Cools
Cambridge University

James Corter
Columbia University

Stephen Crowley
Indiana University

Clayton Curtis
New York University

Carrie Cuttler
Washington State University

Irene Daum
Ruhr University Bochum Germany

Nathaniel Daw
New York University

Mauricio Delgado
Rutgers University–Newark

Dennis Delprato
Eastern Michigan University

Mark D'Esposito
University of California, Berkeley

David Diamond
University of South Florida

Michael Domjan
University of Texas, Austin

Howard Eichenbaum
Boston University

Michael Emond
Laurentian University

William Estes
Indiana University

Marianne Fallon
Central Connecticut State University

Robert Ferguson
Buena Vista University

Julia Fisher
Coker College

John Forgas
University of South Wales

April Fugett
Marshall University

Aubyn Fulton
Pacific Union College

Joaquin Fuster
University of California, Los Angeles

Sherry Ginn
Wingate University

Robert Goldstone
Indiana University

John Green
University of Vermont

Robert Greene
Case Western Reserve University

Pauline Guerin
Pennsylvania State University, Brandywine

Martin Guthrie
Bordeaux University

Lisa Haber-Chalom
Rutgers University–Newark

Karl Haberlandt
Trinity College

Frank Hammonds
Troy University

Stephen Hanson
Rutgers University–Newark

Kent Harber
Rutgers University–Newark

Michael Hasselmo
Boston University

Robert Hawkins
Columbia University

Mohammad Herzallah
Rutgers University—Newark

Kathleen Hipp
Daniel Webster University

Kurt Hoffman
Virginia Tech University

Donald Homa
Arizona State University

Merritt Hoover
University of California—Santa Cruz

Ramona Hopkins
Brigham Young University

Steven Horowitz
Central Connecticut State University

James Hunsicker
Southwestern Oklahoma State University

Dharmananda Jairam
Pennsylvania State University Erie, The Behrend College

Sterling Johnson
University of Wisconsin

Stephen Joy
Albertus Magnus College

Jennifer Joy-Gaba
Virginia Commonwealth University

Lee Jussim
Rutgers University–New Brunswick

Daniel Kahneman
Princeton University

Narinder Kapur
London Memory Clinic

E. James Kehoe
University of South Wales

Szabolcs Kéri
University of Szeged, Hungary

Alan Kersten
Florida Atlantic University

Kristopher Kimbler
Florida Gulf Coast University

Brock Kirwan
Brigham Young University

Alan Kluger
Lehman College, CUNY

Stephen Kosslyn
Harvard University

John Kruschke
Indiana University

Joseph LeDoux
New York University

Dorothea Lerman
University of Houston-Clear Lake

Derick Lindquist
Ohio State University

Elizabeth Loftus
University of California, Irvine

Robert Lubow
Tel-Aviv University

Elliot Ludvig
University of Alberta

Gail Mauner
University at Buffalo, SUNY

James McClelland
Stanford University

Daniel McConnell
University of Central Florida

James McGaugh
University of California, Irvine

Martijn Meeter
Vrije Universiteit Amsterdam, Netherlands

Barbara Mellers
University of California, Berkeley

Earl Miller
Massachusetts Institute of Technology

George Miller
Princeton University

Mortimer Mishkin
National Institutes of Mental Health

John Moore
University of Massachusetts

Lynn Nadel
University of Arizona

Danielle Nadorff
Mississippi State University

Michelle Nicolle
Wake Forest University School of Medicine

Ken Norman
Princeton University

Robert Nosofsky
Indiana University

Laura O'Sullivan
Florida Gulf Coast University

Linda Oliva
University of Maryland, Baltimore County

Ken Paller
Northwestern University

Mauricio Papini
Texas Christian University

Denis Paré
Rutgers University–Newark

Vinay Parikh
Temple University

Nikole Patson
Ohio State University

Marsha Penner
The University of North Carolina at Chapel Hill

Michael Petrides
McGill University

Elizabeth Phelps
New York University

Raymond Phinney
Wheaton College

Steven Pinker
Harvard University

Russell Poldrack
University of California, Los Angeles

Michaela Porubanova
Farmingdale State College, SUNY

Sarah Queller
Indiana University

Sheila Quinn
Salve Regina University

Gabriel Radvansky
University of Notre Dame

Arthur Reber
Brooklyn College, Graduate Center CUNY

Celinda Reese-Melancon
Oklahoma State University

Lisa Rezi
University of Georgia

Trevor Robbins
University of Cambridge

Herbert Roitblat
OrcaTec

Carolyn Rovee-Collier
Rutgers University—New Brunswick

Jerry Rudy
University of Colorado

Linda Rueckert
Northeastern Illinois University

Michelle Ryder
Daniel Webster University

Jeffery Sables
University of Memphis

Sharleen Sakai
Michigan State University

Richard Schiffrin
Indiana University

Ana Schwartz
University of Texas at El Paso

Richard Servatius
VA New Jersey Health Care System and New Jersey Medical School

David Shanks
University College London

Sonya Sheffert
Central Michigan University

Art Shimamura
University of California, Berkeley

Zachary Shipstead
Arizona State University

Daphna Shohamy
Columbia University

Shepard Siegel
McMaster University

Julia Sluzenski
Drexel University

Edward Smith
Columbia University

Patrick Smith
Florida Southern College

Paul Smolensky
Johns Hopkins University

Larry Squire
University of California, School of Medicine, San Diego

Mark Stanton
University of Delaware

Joseph Steinmetz
Indiana University

Greg Stone
Arizona State University

Helen Sullivan
Rider University

Nanthia Suthana
University of California, Los Angeles

Lauren Taglialatela
Kennesaw State University

Paula Tallal
Rutgers University—Newark

Herbert Terrace
Columbia University

Philip Tetlock
University of California, Berkeley

Frederic Theunissen
University of California, Berkeley

Richard Thompson
University of Southern California

Lucy Troup
Colorado State University

Endel Tulving
University of Toronto

Barbara Tversky
Stanford University

Nehal Vadhan
Columbia University Medical School

Anthony Wagner
Stanford University

Jonathon Wallis
University of California, Berkeley

Xiao Wang
University of South Dakota

Mary Waterstreet
Saint Ambrose University

Sheree Watson
University of Southern Mississippi

Daniel Weinberger
National Institutes of Health

Norman Weinberger
University of California, Irvine

J. W. Whitlow, Jr.
Rutgers University—Camden

Andreas Wilke
Clarkson University

James Woodson
University of Tampa

Bonnie Wright
Gardner-Webb University

Diana Younger
University of Texas of the Permian Basin

Laszlo Zaborszky
Rutgers University–Newark

Susan Zelinski
Rutgers University—Newark

Thomas Zentall
University of Kentucky

Acknowledgments, to the Team at Worth Publishers

Textbooks share much in common with Hollywood movies or Broadway shows: the people you see onstage or whose names are on the marquee (or book cover) are only the tip of the proverbial iceberg. Behind them stands a much larger supporting team that is essential to putting on the show. In our case, the two people most central to this book's production and quality are **Daniel DeBonis**, our editor, who served as the effective executive producer of the entire project, managing the various people and components and keeping everyone and everything on track and oriented toward a common vision (and deadline); and **Moira Lerner**, our developmental editor, who functioned like a shadow (but mostly uncredited) fourth author, revising our drafts, identifying problematic gaps in logic and pedagogy, and generally raising the level of coherence, consistency, and communication in the book far beyond what any of the three authors would have been capable of on our own. Special thanks also go to executive marketing manager Kate Nurre for her hard work promoting our book and assistant editor Katie Pachnos for her tremendous attention to detail and help keeping the book on schedule.

Many other people at Worth Publishers provided important contributions to various facets of the book, including Diana Blume, Christine Buese, Rachel Comerford, Lisa Kinne, Tracey Kuehn, Charles Linsmeier, Rachel Losh, Nicole Padinha, Paul Rohloff, Vicki Tomaselli, Catherine Woods, and Kayci Wyatt.

Learning and Memory

The Psychology of Learning and Memory

AT AGE 46, CLIVE WEARING HAD IT ALL. He was a well-known, highly regarded symphony conductor; he was handsome, charming, and witty; and he was deeply in love with his wife, Deborah. Then his memory was stripped from him. Clive had developed a rare condition in which a virus, which usually causes nothing more serious than cold sores, invaded his brain. His brain tissue swelled, crushing against the confines of his skull. Although most patients die when this happens, Clive survived, but his brain remained significantly damaged.

When Clive awoke in the hospital, he had lost most of his past. He could recognize Deborah but couldn't remember their wedding. He knew he had children but couldn't remember their names or what they looked like. He could speak and understand words, but there were huge gaps in his knowledge. On one test, when shown a picture of a scarecrow, he replied: "A worshipping point for certain cultures." Asked to name famous musicians, he could produce four names: Mozart, Beethoven, Bach, and Haydn. Conspicuously absent from this list was the sixteenth-century composer Lassus: Clive had been the world expert on this composer (Wilson & Wearing, 1995).

But Clive Wearing hadn't just lost the past: he'd also lost the present. Now he would remain conscious for only a few seconds of whatever he happened to be experiencing, and then the information would melt away without forming even a temporary memory. During his stay in the hospital, he had no idea where he was or why he was surrounded by strangers. Whenever he caught sight of Deborah—even if she'd only left the room for a few minutes—he'd run to her and kiss her joyously, as if she'd been absent for years.

A few minutes later, he'd catch sight of her again and stage another passionate reunion. Clive now lived "in the moment," caught in an endless loop of reawakening. His numerous journals

Jiri Rezac/Polaris

Clive Wearing with his wife, Deborah.

show his desperate efforts to make sense of what he was experiencing: "7:09 a.m.: Awake. 7:34 a.m.: Actually finally awake. 7:44 a.m.: Really perfectly awake . . . 10:08 a.m.: Now I am superlatively awake. First time aware for years. 10:13 a.m.: Now I am overwhelmingly awake. . . . 10:28 a.m.: Actually I am now first time awake for years. . . ." Each time he added a new entry, he might go back and scratch out the previous line, angry that a stranger had written misleading entries in his journal.

Yet even when Clive knew nothing else, he knew that he loved his wife. Emotional memory—love—survived when almost everything else was gone. And he could still play the piano and conduct an orchestra so competently that a nonmusician wouldn't suspect anything was wrong with Clive's mind. Those specialized skill memories survived, along with more mundane skills, such as making coffee or playing card games. And although Clive was unable to consciously learn any new facts, he could acquire some new habits through repeated practice. After moving to a nursing home, he eventually learned the route from the dining hall to his room, and when prompted to put on his coat for his daily walk past the local pond, he would ask if it was time to go feed the ducks (Wilson & Wearing, 1995). Clive's memory was more like an imperfectly erased blackboard than a blank slate.

Clive Wearing's case is tragic but makes two important points. The first is the unrivaled importance of learning and memory to our lives. Most of the time, we take for granted our memories of who we are and what we know. When these are stripped away, life becomes a series of unrelated moments, isolated from past and future, like those fuzzy moments we all experience when we've just awakened and are disoriented.

The second point is that speaking of memory as if it were a single, cohesive process is misleading. In fact, there are many different kinds of memory, and as with Clive's, some can be damaged while others are spared. Normally, these different kinds of memory function together seamlessly, and we aren't aware of whether a given instance of learning has been preserved as a fact, habit, skill, or emotion. But this cohesion is in many ways an illusion. By confronting the limits of this illusion, we can begin to understand how memory works, both in healthy people and in individuals whose memory has broken down. You will read more about amnesic patients like Clive Wearing in Chapter 7, "Episodic and Semantic Memory: Memory for Facts and Events."

learning. The process by which changes in behavior arise as a result of experiences interacting with the world.

memory. The record of past experiences acquired through learning.

This book is about **learning**, the process by which changes in behavior arise as a result of experience interacting with the world, and **memory**, the record of our past experiences, which are acquired through learning. The study of learning and memory began far back in human history and continues today. Some of humanity's greatest minds have struggled with the question of how we learn and remember. As you read this chapter, you will see why the questions that fascinated philosophers and psychologists of long ago are still relevant today. (For an immediate appreciation of the relevance to your own life, see

"Learning and Memory in Everyday Life" below.) Five themes emerge that have reappeared in different guises across the centuries:

1. How do sensations or ideas become linked in the mind?
2. How are memories built from the components of experience?
3. To what extent are behaviors and abilities determined by biological inheritance (nature) and to what extent by life experiences (nurture)?
4. In what ways are human learning and memory similar to learning and memory in other animals, and in what ways do they differ?
5. Can the psychological study of the mind be rigorously scientific, uncovering universal principles of learning and memory that can be described by mathematical equations and considered fundamental laws?

LEARNING AND MEMORY IN EVERYDAY LIFE

Top Ten Tips for a Better Memory

1. *Pay attention.* Often when we "forget" something, it's not that we've somehow lost the memory of it but that we didn't learn the thing properly in the first place. If you pay full attention to what you are trying to learn, you'll be more likely to remember it later.
2. *Create associations.* Associate what you're trying to learn with other information you already know. For example, it will be easier to remember that Ag is the chemical symbol for silver if you know it is short for *argentum*, the Latin word for "silver." It might also help if you know that Argentina got its name from early European explorers who mistakenly thought the region was rich in silver.
3. *A picture is worth a thousand words.* Names and dates and such are more memorable if you can link them to an image. The effort you expend generating an image strengthens the memory. For example, in an art history course, you might have to remember that Manet specialized in painting figures and his contemporary, Monet, is famous for paintings of haystacks and water lilies. Picture the human figures lined up acrobat-style to form a letter "A" for Manet and the water lilies arranged in a daisy chain to form the letter "O" for Monet.
4. *Practice makes perfect.* There's a reason to drill kindergarteners on their ABCs and make third graders repeatedly recite their multiplication tables. Memories for facts are strengthened by repetition. The same principle holds for memories for skills, such as bike riding and juggling: they are improved by practice.
5. *Use multiple senses.* Instead of just reading information silently, read it aloud. You will encode the information aurally as well as visually. You can also try writing it out; the act of writing activates sensory systems and also forces you to think about the words you're copying.
6. *Reduce overload.* Use memory aids such as Post-it Notes, calendars, or electronic schedulers to remember appointments, due dates, and other obligations, freeing you to focus on remembering items that must be called to mind without written aids—say, during an exam!
7. *Time travel.* Remembering information for facts doesn't depend on remembering the exact time and place where you acquired it. Nevertheless, if you can't remember a fact, try to remember where you first heard it. If you can remember your high school history teacher lecturing on Napoleon, perhaps what she said about the causes of the Napoleonic Wars will also come to mind.
8. *Get some sleep.* Two-thirds of Americans don't get enough sleep. Consequently, they are less able to concentrate during the day, which makes it harder for them to encode new memories and retrieve old ones (see Tip 1). Sleep is also important for helping the brain organize and store memories.
9. *Try a rhyme.* Do you have to remember a long string of random information? Create a poem (or better yet, a song) that includes the information. Remember the old standards "'I' before 'E' except after 'C' or sounded as 'A,' as in 'neighbor' or 'weigh'"? This ditty uses rhythm and rhyme to make it easier to remember a rule of English spelling.
10. *Relax.* Sometimes trying hard to remember is less effective than turning your attention to something else; often, the missing information will pop into your awareness later. If you are stumped by a question on a test, skip that one and come back to it later, when perhaps the missing information won't be so hard to retrieve.

1.1 From Philosophy and Natural History to Psychology

Today, learning and memory researchers consider themselves scientists. They develop new theories and test those theories with carefully designed experiments, just like researchers in any other branch of science. However, this wasn't always the case. In fact, for most of human history, the study of learning and memory was a branch of *philosophy*, the abstract study of principles that govern the universe, including human conduct. Philosophers gain insight not through scientific experiments but through a process of reasoned thought and logical argument. These insights may be no less important than those gained through modern science; some are so profound that people continue talking about them centuries after they were first disseminated.

The Empiricism and Associationism of Aristotle

Aristotle (384–322 BC), a Greek philosopher and teacher, was one of the earliest thinkers to write about memory. Like many wealthy young men of his day, Aristotle was educated in Athens, the preeminent intellectual center of the western world at that time. There, he studied under Plato (c. 427–347 BC), perhaps the greatest of the Greek philosophers. Years later, Aristotle himself became a mentor to many students, including the young prince later known as Alexander the Great, who went on to conquer much of the world.

data. Facts and figures from which conclusions can be inferred.

theory. A set of statements devised to explain a group of facts.

associationism. The principle that memory depends on the formation of linkages ("associations") between pairs of events, sensations, and ideas, such that recalling or experiencing one member of the pair elicits a memory or anticipation of the other.

contiguity. Nearness in time (temporal contiguity) or space (spatial contiguity).

A keen observer of the natural world, Aristotle loved **data**, the facts and figures from which he could infer conclusions. He collected plants and animals from around the world and made careful notes about their structure and behavior. From such data, Aristotle attempted to formulate **theories**, sets of statements devised to explain a collection of facts. His data-oriented approach to understanding the world stood in marked contrast to the methods of his intellectual forebears, including Plato and Plato's teacher, Socrates, both of whom relied primarily on intuition and logic rather than natural observation.

One of Aristotle's key interests was memory. His theory about it, called **associationism**, argued that memory depends on the formation of linkages ("associations") between pairs of events, sensations, or ideas, so that recalling or experiencing one member of the pair elicits a memory or anticipation of the other. Imagine someone reading a list of words and for each word asking you to say the first word that comes to mind. If he says "hot," you might say "cold"; if he says "chair," you might say "table," and so on. The words "hot" and "cold" are linked, or associated, in most people's minds, as are "table" and "chair." How do these associations come about?

Aristotle described such linkages as reflecting three principles of association. The first principle is **contiguity**, or nearness in time and space: events experienced at the same time (temporal contiguity) or place (spatial contiguity) tend to be associated. The ideas of "chair" and "table" are linked because we often see chairs and tables together at the same time and in the same place. The second principle is *frequency*: the more often we experience events that are contiguous, the more strongly we associate them. Thus, the more often we see tables and chairs together, the stronger the table–chair link grows. Modern behavioral and neurobiological studies of the interaction between contiguity and frequency in learning will be discussed further in Chapter 4, "Classical Conditioning: Learning to Predict Significant Events."

Aristotle's third principle is *similarity*: if two things are similar, the thought or sensation of one will tend to trigger a thought of the other. Chairs and tables

are similar in that both are often made of wood, both are found in kitchens, and both have a function associated with eating meals. This similarity strengthens the association between them. In Chapter 6, "Generalization, Discrimination Learning, and Concept Formation," you will see why similarity has continued to be a core focus of research on learning. Together, Aristotle concluded, these three principles of association—contiguity, frequency, and similarity—are the basic ways humans organize sensations and ideas.

Aristotle's ideas, refined in the ensuing two millennia, have provided the foundation for modern theories of learning in both psychology and neuroscience. Aristotle's view was that knowledge emerges from experience. This idea identifies him with a philosophical school of thought known as **empiricism**, which holds that all the ideas we have are the result of experience. (The Greek word *empiricus* means "experience.") To Aristotle, the mind of a newborn child is like a blank slate, not yet written on.

In this regard, Aristotle differed sharply from his teacher Plato, who believed staunchly in **nativism**, which holds that the bulk of our knowledge is inborn (or native). Plato's most influential book, *The Republic*, described an idealized society in which people's innate differences in skills, abilities, and talents form the basis for their fixed roles in life: some rule while others serve. The tension between empiricism and nativism has continued through the centuries, although today it is more often called the "nature versus nurture" debate: researchers argue about whether our "nature," including genes, or our "nurture," including upbringing and environment, has the greater influence on our learning and memory abilities. Table 1.1 shows some of the major philosophers and scientists who have contributed to this debate over the millennia and which side of the debate they espoused; the names and ideas in the table will be revisited throughout the book.

Scala/Art Resource, NY

Aristotle (right) and his teacher, **Plato**

empiricism. A philosophical school of thought that holds that all the ideas we have are the result of experience.

nativism. A philosophical school of thought that holds that the bulk of knowledge is inborn (or native).

Western philosophy and science have deep roots in the ideas and writings of the ancient Greeks, whose philosophy and science continued to flourish under the Roman Empire. By the fifth century AD, however, the empire had collapsed, and Europe plunged into the Dark Ages, overrun by successive waves of warring tribes who seemed to care little for philosophy or learning. (Meanwhile, in China, India, Persia, and the Arabian Peninsula, flourishing civilizations achieved major advances in science, mathematics, medicine, and astronomy—but that's another story.) It was not until the middle of the fifteenth century that European science flourished once again. This was the Renaissance, the era that brought forth the art of Leonardo da Vinci, the plays of William Shakespeare, and the astronomy of Nicolaus Copernicus and Galileo Galilei. This cultural and scientific revival set the stage for the emergence of new ideas about the nature of mind and memory.

Descartes and Dualism

René Descartes (1596–1650) grew up in France as the son of a provincial noble family. His family inheritance gave him the freedom to spend his life studying,

Table 1.1 Nativism and empiricism: The role of nature and nurture in learning and memory

Nativism: Knowledge is inborn	Empiricism: Knowledge is acquired through experience
Plato (c. 427–347 BC) Most of our knowledge is innate.	**Aristotle (384–322 BC)** Memory depends on the formation of associations, for which there are three principles: contiguity, frequency, and similarity.
René Descartes (1596–1650) The mind and the body are distinct entities, governed by different laws. The body functions as a machine with innate and fixed responses to stimuli.	**John Locke (1632–1704)** A newborn's mind is a blank slate (a *tabula rasa*) that is written on by experience. Education and experience (learning) allow common people to transcend their class.
Gottfried Leibniz (1646–1716) Three quarters of human knowledge is learned, but one quarter is inborn.	**William James (1842–1910)** Habits are built up from inborn reflexes through learning; memory is built up through networks of associations.
Charles Darwin (1809–1882) Natural selection: species evolve when they possess a trait that is inheritable, varies across individuals, and increases the chances of survival and reproduction.	**Ivan Pavlov (1849–1936)** In classical (Pavlovian) conditioning, animals learn through experience to predict future events.
	Edward Thorndike (1874–1949) The law of effect (instrumental conditioning): an animal's behaviors increase or decrease depending on the consequences that follow the response.

Musée des Augustins, Toulouse, France/The Bridgeman Art Library

René Descartes

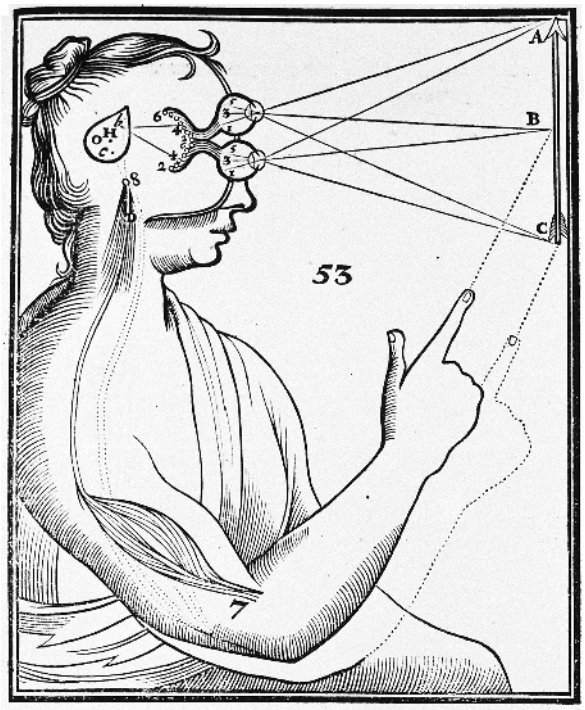
thinking, and writing, most of which he did in bed (he hated to get up before noon). Although raised as a Roman Catholic and trained by the Jesuits, Descartes harbored deep doubts about the existence of everything. Despairing of being able to know anything for certain, he concluded that the only evidence that he himself even existed was his ability to think: "*Cogito ergo sum*," or "I think, therefore I am" (Descartes, 1637).

Where does Descartes' *cogito*—the ability to think—come from? Descartes was a firm believer in **dualism**, the principle that the mind and body exist as separate entities, each with different characteristics, governed by its own laws (Descartes, 1662). The body, Descartes reasoned, functions like a self-regulating machine, much like the clockwork statues and fountains that were so fashionable during the Renaissance. A person strolling through the royal gardens of Saint-Germain-en-Laye, just outside Paris, would step on a hidden trigger, releasing water into pipes that caused a gargoyle to nod its head, a statue of the god Neptune to shake its trident, and the goddess Diana to modestly retreat. The body, Descartes reasoned, works through a similar system of hydraulics and switches. The process begins when a **stimulus**, a sensory event from the outside world, enters the system; for example, light reflected off a bird enters the eye as a visual stimulus. Like the trigger switch in the gardens, this stimulus causes fluids (Descartes called them "spirits") to flow through hollow tubes from the eyes to the brain and then to be "reflected" back as an outgoing motor

response, the behavioral consequence of perception of the stimulus, as illustrated by Descartes' sketch in Figure 1.1 (Descartes, 1662). Such a pathway from sensory stimulus to motor response is called a **reflex arc**.

Descartes got many of the details of reflexes wrong. There are no spirits that flow through the body to produce movement hydraulically as he described. Nevertheless, Descartes was the first to show how the body might be understood through the same mechanical principles that underlie physical machinery. This mechanistic view of the processes that give rise to behavior returned in full force many centuries later in the mathematical and computer models of the brain and behavior described in several of the chapters in this book.

In contrast to Aristotle, who believed knowledge was attained through experience, Descartes was strongly in the nativist camp with Plato. Descartes had no interest in theories of learning. He acknowledged that people do derive some information from experience, but he believed that much of what we know is innate. The nature–nurture debate continues today to inform our efforts at understanding how and to what degree we are able to change and evolve within the span of our own lifetimes, a topic covered in Chapter 12, "Development and Aging: Learning and Memory across the Lifespan."



Corbis

Figure 1.1 Descartes' reflex A mechanism for producing an automatic reaction in response to external events, as illustrated in Descartes' *De Homine* (1662). The diagram shows the flow of information from the outside world, through the eyes, to the brain, and then through the muscles of the arm, creating a physical response in which the arm moves to point to an object in the external world.

John Locke and His Reliance on Empiricism

By the late 1600s, England (along with the rest of Europe) had undergone the conflicts of the Reformation, a religious and political movement that weakened the political power of the Roman Catholic Church and placed new emphasis on individual rights and responsibilities. This was a period when science flourished. Famous scientists were the celebrities of their day; people attended lectures on philosophy and natural sciences the way they now go to movies and rock concerts. One especially renowned scientist, Isaac Newton, demonstrated that white light can be refracted into component colors by a prism lens and then recombined by another lens to produce white light again.

Inspired by Newton's work, John Locke (1632–1704) hoped to show that the mind, too, could be broken down into elements that when combined produced the whole of consciousness. Locke, like Descartes before him, borrowed methods from the physical sciences that would help him better understand the mind and the processes of learning and memory. This practice of philosophers and psychologists of borrowing from other, more established and rigorous domains of science continues to this day.

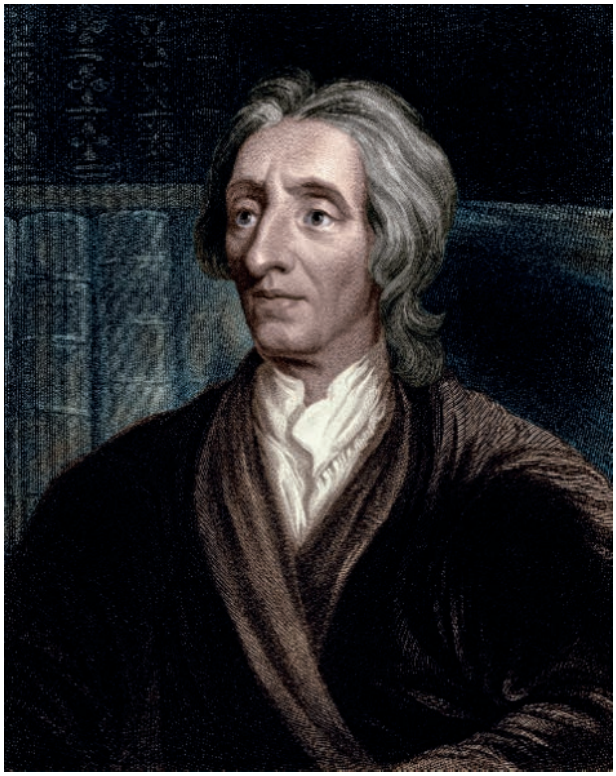
To describe the way elementary associations might account for the more complex ideas and concepts that make up our memories and knowledge, Locke drew from the work of his former Oxford medical instructor, Robert Boyle, who 30 years before had demonstrated that chemical compounds are composed of elementary parts (what we now know to be molecules and atoms). Locke reasoned that complex ideas are similarly formed from the combination of more elementary ideas that we passively acquire through our senses (Locke, 1690). For example, simple ideas such as "red" and "sweet" are acquired automatically by our senses of sight and taste, and more complex ideas such as "cherry" are acquired by combining these simpler components.

dualism. The principle that the mind and body exist as separate entities.

stimulus. A sensory event that provides information about the outside world.

response. The behavioral consequence of perception of a stimulus.

reflex arc. An automatic pathway from a sensory stimulus to a motor response.



INTERFOTO/Alamy

John Locke

Perhaps Locke's most lasting idea is that all knowledge is derived from experience. Borrowing Aristotle's analogy of a tablet on which nothing is yet written, Locke suggested that children arrive in the world as a blank slate or tablet (in Latin, a *tabula rasa*) just waiting to be written on.

Locke's view of the power of experience to shape our capabilities through a lifetime of learning had great appeal to reformers of the eighteenth century, who were challenging the aristocratic system of government, in which kings ruled by right of birth. Locke's ideas meant that a man's worth was not determined at birth. All men are born equal, he believed, with the same potential for knowledge, success, and leadership. Common people, through striving and learning, could transcend the limits and barriers of class. Therefore, Locke argued, access to a good education should be available to all children regardless of their class or family wealth (Locke, 1693). These ideas heavily influenced Thomas Jefferson as he drafted the Declaration of Independence, which in 1776 proclaimed the American colonies' independence from Great Britain and asserted that "all men are created equal," with the same innate rights to "life, liberty, and the pursuit of happiness"—words taken almost verbatim from Locke's writings.

Although Locke's writings were influential throughout European philosophical and scientific circles, he was not without his critics. One of Locke's contemporaries, German mathematician Gottfried Wilhelm Leibniz (1646–1716), conceded to Locke that three quarters of knowledge might be acquired but claimed that the other quarter is inborn and innate, including habits, predispositions, and potentials for success or failure (Leibniz, 1704). In many ways, Leibniz's more moderate position echoes that adopted by many modern researchers, who believe that human ability is not due solely to nature (nativism) or solely to nurture (empiricism) but is a combination of both: nature (as encoded in our genes) provides a background of native ability and predispositions that is modified by a lifetime of experience and learning (nurture).

William James and Associationism

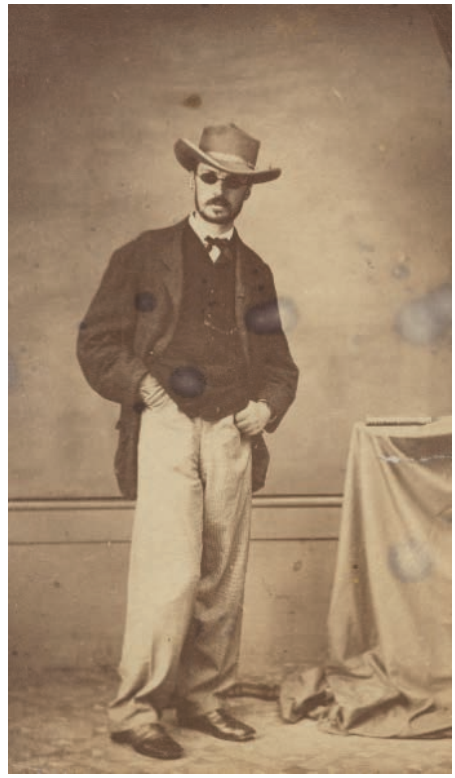
Born to a wealthy and prominent New York family, William James (1842–1910) spent his early years traveling around the world, living in fine hotels, and meeting many of the great writers and philosophers of his time. After receiving his medical degree in 1869, James accepted a position as an instructor of physiology and anatomy at Harvard, where he offered an introductory course in **psychology**, the study of mind and behavior. It was the first course on psychology ever given at Harvard or at any college in America. He once joked that the first psychology lecture he heard was his own.

psychology. The study of mind and behavior.

James's introductory psychology course soon became one of the most popular courses at Harvard, and he signed a contract with a publisher, promising to deliver within two years a book based on his acclaimed lectures. In the end, it took him 12 years to finish the book. James's two-volume *Principles of Psychology* (1890) was an immediate scientific, commercial, and popular success. Translated into many languages, it was for decades the standard psychology text around the world.

James was especially interested in how we learn new habits and acquire new memories. He enjoyed telling the story of a practical joker who, seeing a recently discharged army veteran walking down the street carrying a load of groceries, shouted, "Attention!" The former soldier instantly and instinctively brought his hands to his side and stood ramrod straight as his mutton and potatoes rolled into the gutter. The soldier's response to this command was so deeply ingrained as a reflex that, even after he had left the army, it was all but impossible to suppress. James believed that most abilities and habits were similarly formed by our experiences, especially early in life. He proposed that a central goal of psychology should be to understand the principles that govern the formation and maintenance of new skills and memories, including how and why old learning may block or facilitate the formation of new learning (James, 1890); indeed, this tension between old memories and new learning has been an ongoing focus of experimental psychology in the last century, as reviewed in many of the chapters to follow, especially Chapter 7, "Episodic and Semantic Memory: Memory for Facts and Events," and Chapter 8, "Skill Memory: Learning by Doing."

James was a strong proponent of associationism, and his theories elaborated on the work of Aristotle and Locke. The act of remembering an event, such as a dinner party, he wrote, would involve multiple connections between the components of the evening. These might include memories for the taste of the food, the feel of his stiff dinner jacket, and the smell of the perfume of the lady seated next to him (Figure 1.2). Activation of the memory for the dinner party, with all of its components, could in turn activate the memory for a second



(MS Am 1092.) Houghton Library, Harvard University

William James

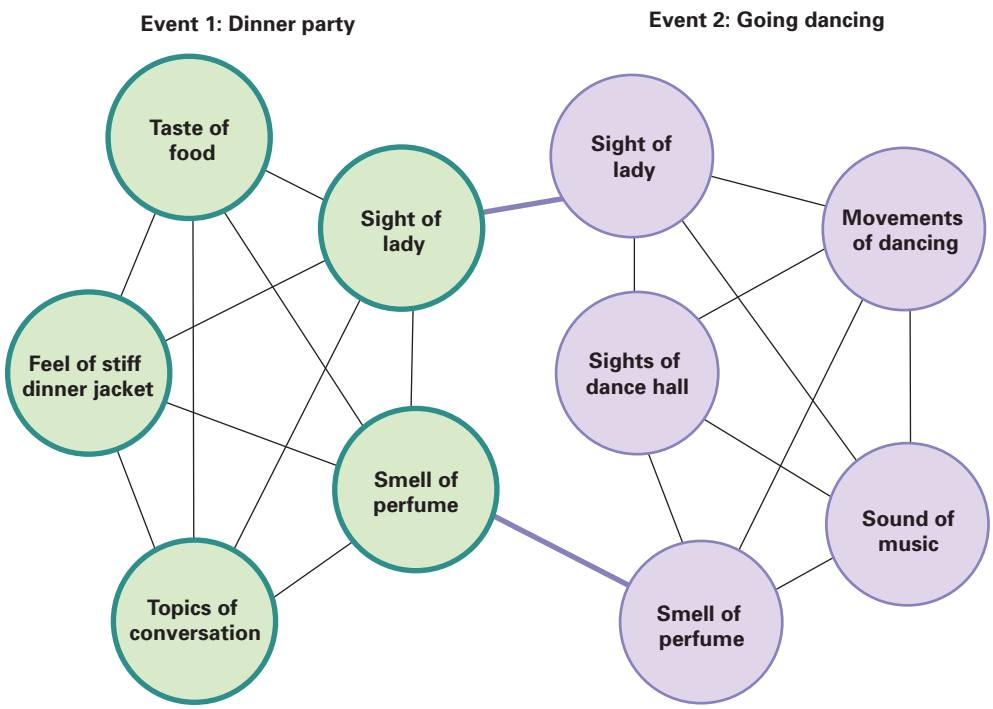


Figure 1.2 William James's memory model
Memory of an event, such as a dinner party, has multiple components all linked together. Another event, such as going dancing with a lady from the dinner party, also has component parts linked together. A mental association between the two events in turn consists of multiple connections between the underlying components.