

Learning and Memory

From Brain to Behavior

SECOND EDITION

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Learning and Memory

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To the mother of all my memories, Doris H. Gluck
M. A. G.

To my daughter, Amalia
E. M. III

To William, as I watch his young mind grow and learn
C. E. M.

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This is the second edition of *Learning and Memory: From Brain to Behavior*, following the success of our first edition, published in 2008. The new edition continues our approach of presenting a comprehensive, accessible, and engaging introduction to the scientific study of learning and memory. The biggest change we have introduced in the second edition is the adapting of chapters into a new, modular table of contents that 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. This new organization, in which the book as a whole is divided into conceptual modules consisting of from two to four chapters each, extends the theme established in the first edition (and continued here) in which all the core chapters have the same three subsections: Behavioral Processes, Brain Substrates, and Clinical Perspectives. As explained in more detail below, the innovative organization of our second edition results in a highly flexible curriculum suited to the many different ways that teachers prefer to teach this material. Other notable changes since the first edition include

- *Increased use of real-world examples*, concrete applications, and clinically relevant perspectives.
- *Enhancement and integration of 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.
- *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.
- *Expanded tutorial discussions of anatomy and biochemistry* for students with little or no biology background.
- *Even more integration of topics across chapters*, highlighting connections between themes and concepts that arise repeatedly in different parts of the book.
- *About 20% new references*, reflecting rapid recent advances in the field and emphasizing important breakthroughs in all aspects of learning and memory research since the publication of the first edition in 2008.

As detailed in the following discussions, *Learning and Memory: From Brain to Behavior*, 2nd Edition, is notable among textbooks in its field for the flexibility of its novel modular structure and for its strong neuroscience focus, integrative coverage of animal learning and human memory, engaging writing style, helpful pedagogical features incorporated throughout each chapter, 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—New for 2nd Edition

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 understandable 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 the introduction this year of *Learning and Memory: From Brain to Behavior*, 2nd Edition, there is now available, for the first time, 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 non-associative learning (primarily habituation and sensitization); classical conditioning; instrumental 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*, 2nd 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, Huntington's disease, dyslexia, 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.

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.
- **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** with page references appear at the end of each chapter to help students review new terminology presented in the chapter. All key terms with their definitions are included in an end-of-text glossary.

Media/Supplements

Book Companion Site at www.worthpublishers.com/gluck2e

The companion site serves students as a virtual study guide, 24 hours a day, 7 days a week. The password-protected instructor's section offers a variety of assessment, presentation, and course management resources.

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 instructor's side of the Book Companion Site.

Instructor's Resource Manual and Test Bank

The Instructor's Resource Manual 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. The Test Bank features approximately 100 questions per chapter as well as an assortment of short-answer and essay questions. Also included in the Test Bank are the chapter-specific Web quizzes (10–15 questions each) that appear on the Book Companion Site.

Diploma Computerized Test Bank (Available in Windows and Macintosh on one CD-ROM)

The Test Bank 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 grade book, 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, prebuilt 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 reflects a contemporary perspective on the field.

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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 the herpes simplex 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.

From Philosophy to Psychology

Learning and Memory in Everyday Life: Top Ten Tips for a Better Memory

The Empiricism and Associationism of Aristotle

Descartes and Dualism

John Locke and His Reliance on Empiricism

William James and Associationism

Evolution and Natural Selection

Charles Darwin and the Theory of Natural Selection

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Hermann Ebbinghaus and Human Memory Experiments

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Edward Thorndike and the Law of Effect

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John Watson's Behaviorism

Clark Hull and Mathematical Models of Learning

B. F. Skinner's Radical Behaviorism

The Neo-Behaviorism of Edward Tolman

The Cognitive Approach

W. K. Estes and Mathematical Psychology

Gordon Bower: Learning by Insight

George Miller and Information Theory

The Connectionist Models of David Rumelhart



Jiri Rezac, 2005

Clive Wearing with his wife,
Deborah

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 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 happened in Clive's case, 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, “Semantic and Episodic Memory: Memory for Facts and Events.”

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, we hope that you will see why the questions that fascinated philosophers and psychologists of long ago are still relevant today. Some of the insights may apply to your own efforts to improve your memory at school and in other aspects of your daily life. To whet your appetite, see “Learning and Memory in Everyday Life” on page 4.

In the course of this chapter, five themes emerge that have reappeared in different guises across the centuries. These five themes are

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. Are there universal principles of learning and memory that can be described by mathematical equations and considered fundamental laws?

1.1 From Philosophy 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.

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 standard “ ‘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.

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 a young prince later known as Alexander the Great, who went on to conquer much of the world.

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.

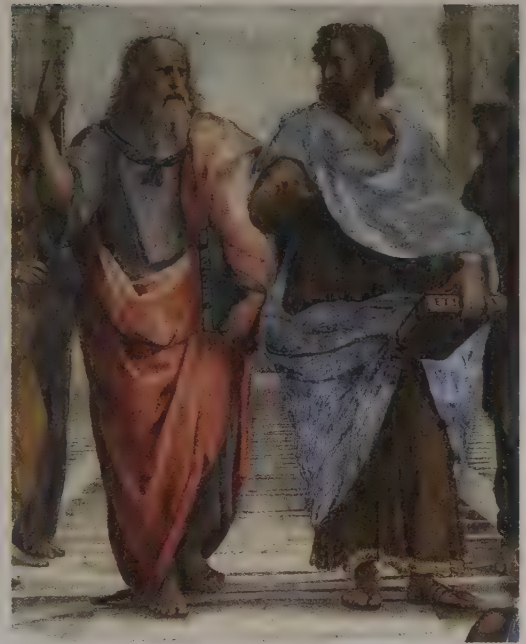
One of Aristotle's key interests was memory. His theory about it, called **associationism**, argued that memory depends on the formation of linkages ("associations") between pairs of events, sensations, or ideas, so that recalling or experiencing one member of the pair elicits a memory or anticipation 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 Important 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 and Discrimination Learning," 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), acquired during the past lifetimes of our eternal souls. In fact, Plato's most influential book, *The Republic*, describes 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



Aristotle (right) and his teacher, Plato

Table 1.1**Nativism and empiricism: The role of nature and nurture in learning and memory****Nativism: Knowledge is inborn****Plato (c. 427–347 BC)**

Most of our knowledge is inborn and acquired during past lifetimes of the soul.

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.

Gottfried Leibniz (1646–1716)

Three quarters of human knowledge is learned, but one quarter is inborn.

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.

Francis Galton (1822–1911)

Humans' natural talents are hereditary.

Empiricism: Knowledge is acquired through experience**Aristotle (384–322 BC)**

Memory depends on the formation of associations, for which there are three principles: contiguity, frequency, and similarity.

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.

William James (1842–1910)

Habits are built up from inborn reflexes through learning; memory is built up through networks of associations.

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.

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.

1 René Descartes

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

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, 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, including

God. 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 engineering models of the brain and behavior described in several of the chapters in this book.

In contrast to Aristotle, who was a staunch empiricist, 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.”

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

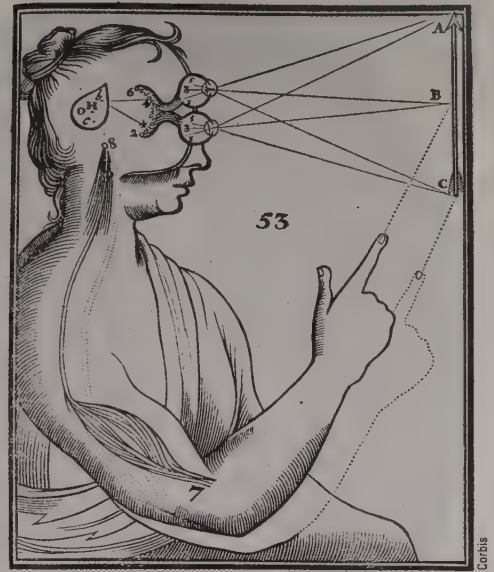


Figure 1.1 Descartes’ reflex A mechanism for producing an automatic reaction in response to external events, as illustrated in Descartes’ *De Homine* (1662). The diagram shows the flow of information from the outside world, through the eyes, to the brain, and then through the muscles of the arm, creating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



| John Locke

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, as summarized in Table 1.2.

How did Locke envision the way elementary associations might account for the more complex ideas and concepts that make up our memories and knowledge? By once again drawing inspiration from the physical sciences, this time from 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.

Perhaps Locke's most lasting idea is that all knowledge is derived from experience and experience alone. Borrowing Aristotle's analogy of a tablet on which

Table 1.2

Borrowing from the physical and natural sciences to explain the mind

Who . . .	Borrowed Ideas from . . .
René Descartes	Hydraulic engineering
John Locke	Physics (Newton), chemistry (Boyle)
Hermann Ebbinghaus	Laws of perception (Fechner and Weber)
Ivan Pavlov	Telephone exchanges
Edward Thorndike	Evolution by natural selection (Darwin)
Clark Hull	Theory of relativity (Einstein)
George Miller	Information theory (Shannon)
Herbert Simon	Computer science
David Rumelhart	Neuroscience and computer science

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) alone 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

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 ever heard was his own.

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, "Semantic and Episodic 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 event that shared some related elements—such as a visit to a dance hall with the same lady on the next night. This second event would be composed of its own parts: the sights of the dance hall, the movements of dancing, the smell of his partner's perfume, and so on. The two events (dinner party and dancing) would be associated by a linkage between their common or related components (the sight of the lady and the smell of her perfume).

This model, or simplified description, of memory was one of James's many seminal contributions to psychology. James took his model literally, believing that the associations it described would eventually be mapped directly onto physical connections in the brain (James, 1890). With this idea, James was far

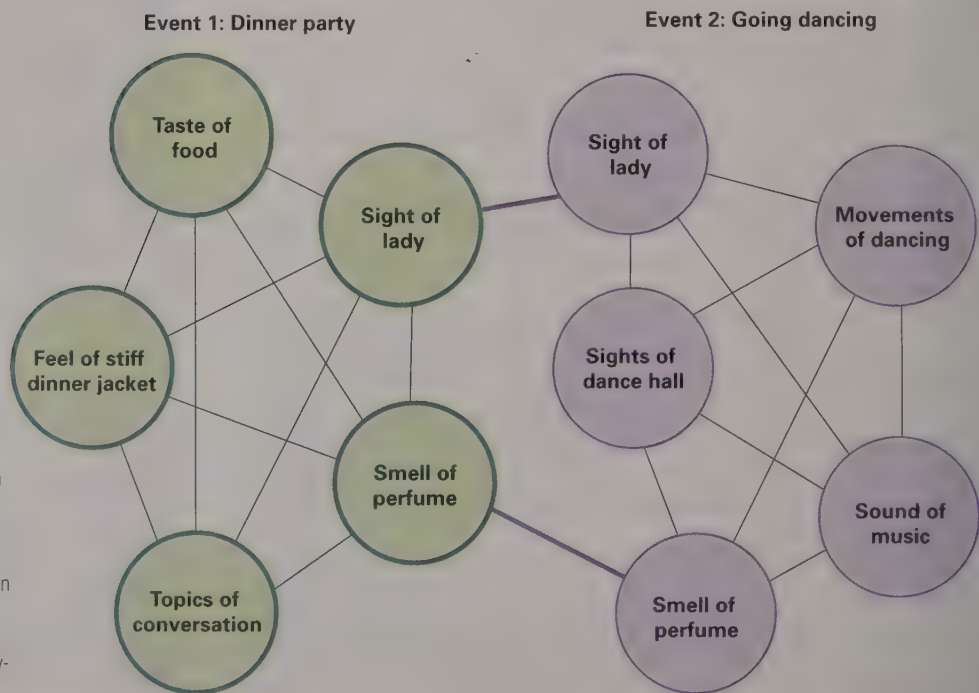


Figure 1.2 William James's memory model

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.

ahead of his time: linking brain processes to learned behaviors didn't attract much interest for many decades. Today, most modern theories of memory draw on James's idea of learning as a process of forming associations between the elements of an experience, as you will see in many chapters to come, including Chapter 4, "Classical Conditioning: Learning to Predict Important Events," and Chapter 7, "Semantic and Episodic Memory: Memory for Facts and Events."

Interim Summary

- Early philosophers interested in learning and memory wrestled with many key issues that are still central to modern theories.
- Aristotle was an associationist, believing that the effects of experiences can be understood as associations formed between sensations or ideas. He described three key principles of associative learning: contiguity (in space and time), frequency, and similarity. A later associationist, William James, proposed an early and influential memory model built on similar principles.
- John Locke, like Aristotle and James, was an empiricist: he believed that we are all born equal, as blank slates, to be shaped by our experiences. In contrast, René Descartes was a nativist, arguing that we are shaped primarily by our inherited nature. He argued that the body could be understood as a machine that works through mechanical (especially hydraulic) principles; as a dualist, he believed that the mind was a separate entity from the body.
- Modern researchers are less likely to be strict nativists or strict empiricists and are more likely to accept that both nature (genes) and nurture (experience) play a role in human learning and memory.

1.2 Evolution and Natural Selection

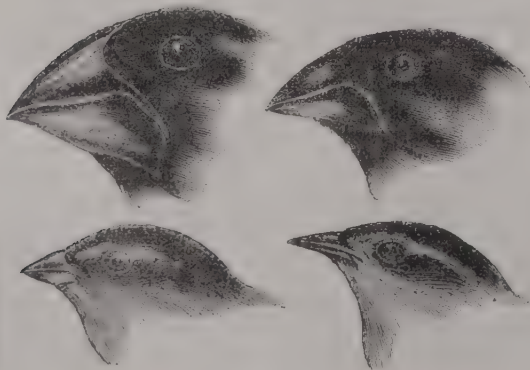
How unique are humans within the animal kingdom? Plato and other early Greek philosophers took one extreme view: they believed that humans are unique among living things because they possess an everlasting soul. Aristotle, in contrast, argued that humans exist in a continuum with other animals and that the ability to reason is their sole distinguishing feature. Renaissance philosophers tended to side with Plato, bolstered by the Church-sponsored view that mankind was created in God's image. For example, Descartes believed that humans and animals are fundamentally different, just as he believed that mind and body are separate.

But by the early 1800s, this view of humans as being fundamentally different from animals was beginning to meet serious challenge. European naturalists had begun to collect and study a wide variety of plants and animals from around the world. The geological study of rock formations that are shaped by eons of water movement, along with fossils found embedded in these rocks, suggested a world millions of years old. What naturalists and geologists saw in their studies contradicted the prevailing belief that the world was stable and unchanging. The facts they uncovered and the theories they developed upended many long-held beliefs about who we are, where we come from, and how similar we really are to other animals. These new perspectives on the relationship between animals and humans would profoundly affect all future studies of the psychology of learning and memory.



Charles Darwin

Figure 1.3 Finches of the Galápagos Islands Note the strong, heavy beak of the bird at the upper left (good for cracking nuts) and the long, narrow beak of the bird at the lower right (good for grabbing insects from cracks in bark).



Erasmus Darwin (1731–1802) was the personal doctor to King George III of England, who presided over the loss of the American colonies. A man of diverse interests, Darwin wrote books of poetry as well as books on botany and studied how the application of an electrical current to the muscle of a dead animal could cause the muscle to contract and move as if it were alive. This finding inspired his English contemporary Mary Wollstonecraft Shelley (1797–1851) in writing her classic horror story, *Frankenstein*. But Erasmus Darwin is best remembered as a vocal proponent of **evolution**, the theory that species change over time, with new traits or characteristics emerging and being passed from one generation to the next. With sufficient time, he argued, one species could evolve so far that it would come to constitute an entirely different species from its ancestor (E. Darwin, 1794). It was many years later, however, that Erasmus's grandson Charles developed a theory of how this evolutionary process might take place and in doing so made the term “evolution” synonymous with the name Darwin.

Charles Darwin and the Theory of Natural Selection

Charles Darwin (1809–1882) was Erasmus Darwin's grandson. Charles's father was a prosperous doctor, and his mother hailed from the wealthy Wedgwood family of ceramic ware fame. Expected to become a doctor like his father, Darwin began his medical studies, but he soon dropped out, nauseated by watching patients undergo surgery without anesthesia. Fortunately, his family's financial position meant that he didn't have to work for a living. Instead, what Darwin most enjoyed was to walk through the English countryside collecting and cataloging animals.

In 1831, at age 22, with no career direction other than his amateur interest in natural history, Charles Darwin accepted an offer to accompany the captain of the HMS *Beagle* on an expedition to chart the coast of South America. The *Beagle's* voyage was scheduled to last for two years, but it stretched into five. In South America, Darwin encountered an abundance of previously unknown species, many on the Galápagos Islands, an isolated archipelago off the coast of Ecuador. Of particular interest to Darwin were the many species of birds he observed, especially the finches—of which he identified at least 14 varieties, each on a different island (Figure 1.3). On one island that had plentiful nuts and seeds, the finches had strong, thick beaks that they used to crack open nuts. On another island, with few nuts but plenty of insects, the finches had long, narrow beaks, perfect for grabbing insects from the crevices of tree bark. Each isolated island in the archipelago was populated by a different kind of finch, with a beak ideally suited to that island's distinct habitat. In his account of the trip, Darwin wrote that “one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends” (C. Darwin,

Table 1.3**Darwin's three criteria for traits to evolve through natural selection**

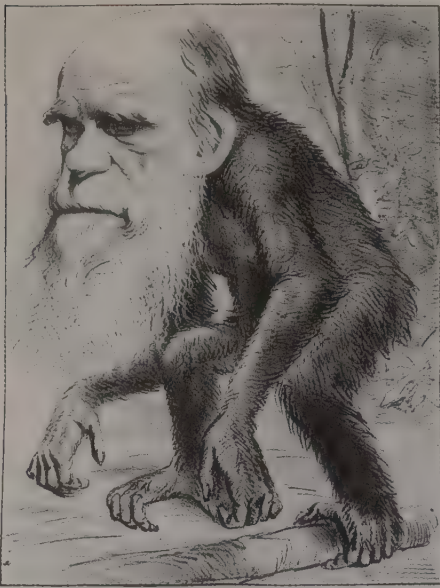
Criterion	Giraffes	Finches
1. Inheritable trait	Neck length	Beak shape
2. Natural variability	Short to long	Thin or thick
3. Relevance to survival	Longer necks allow greater access to high branches of trees, and thus to leaves	Correct shape improves access to insects (thinner beak) or ability to crack nuts (thicker beak)

1845). Charles Darwin, like his grandfather, was convinced that life on earth was evolving and was not immutably fixed.

Darwin's most important legacy was his theory of **natural selection**, which proposed a mechanism for how evolution occurs (C. Darwin, 1859). He proposed that species evolve when they possess a trait that meets three conditions (Table 1.3). First, the trait must be inheritable, meaning it can be passed from parent to offspring. (Keep in mind that genes—the carriers of inherited traits—had not yet been discovered in Darwin's time.) Second, the trait must vary, having a range of forms among the individual members of the species. Third, the trait must make the individual more “fit,” meaning that it must increase reproductive success—that is, increase the chance that the individual will survive, mate, and reproduce, passing on the trait to its offspring. This, in turn, will make the offspring more fit, increasing their chances of surviving and passing on the trait. Over time, natural selection (sometimes called “survival of the fittest”) means that the trait will spread through the population. This, Darwin argued, was the underlying mechanism by which species evolve.

Darwin tinkered with his ideas for 20 years. Finally, in 1859, he published *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*, more commonly known by its abbreviated title, *The Origin of Species*. Darwin's book became a best seller, was translated into many languages, and ignited a major public controversy that resulted in thousands of reviews, articles, and satires. Why the uproar? Darwin's view of natural selection upset many people's view that there is an important distinction between “man and beast.” Theologians were alarmed because the idea that humans and apes evolved from a common ancestor seemed to challenge the biblical doctrine that people were created by the hand of God, in God's own image. *The Origin of Species* is among the most controversial scientific books ever written.

What are the implications of Darwin's work for the psychology of learning and memory? Darwin argued that behavioral traits could evolve through the same process of natural selection as do physical traits (C. Darwin, 1872). Today, the study of how behavior evolves through natural selection is known as **evolutionary psychology**. The basic premise of evolutionary psychology is that learning has enormous value for survival, allowing organisms to adapt to a changing and variable world. Organisms with more capacity for learning and memory are more fit—better able to survive and more likely to breed and pass their inherited capacities on to offspring. Notice that the content of what is learned is not passed on: learned knowledge is an acquired trait, which cannot



Following publication of *The Origin of Species* in 1859, Darwin was the subject of many personal attacks, including caricatures as a half man/half ape, as in this illustration from *Hornet* magazine (March 22, 1871).

Francis Galton



be inherited. What can be inherited is the capacity or ability for learning and memory. Further discussion of evolutionary theory, and the revolution in genetics that it spawned, will be covered in Chapter 12, “Development and Aging: Learning and Memory across the Lifespan.”

Francis Galton and the Variability of Nature

Francis Galton (1822–1911) was another grandson of Erasmus Darwin. A precocious child, Galton learned to read before he was 3 years old, wrote his first letter at 4, and spoke several languages by the time he was 5. After traveling for several years through African jungles and deserts, he returned to England, fascinated by the enormous variability he had seen in human characteristics. He began to measure everyone he could, comparing mental powers, auditory acuity, physical size, even fingerprints (and, in doing so, invented the modern police method of fingerprinting).

Inspired by his cousin Charles Darwin’s theory of natural selection and survival of the fittest, Galton proposed that “a man’s natural abilities are derived by inheritance” (Galton, 1869,

p. 1). Galton soundly rejected Locke’s (and Aristotle’s) view of the blank slate. It is a “fairy tale,” he wrote, “that babies are all born pretty much alike” (p. 14). In no uncertain terms, Galton—who viewed himself as a genius—railed against the idea of natural equality. Was he himself, and his erudite forebears, not proof that great talent is innate and runs in families, preserved across generations?

As a by-product of his comparative studies of people’s physical and mental abilities, Galton invented much of modern statistical and scientific methodology. He found that many attributes—such as height or blood pressure or scores on memory tests—show what he termed a *normal distribution*: out of a large sample of measurements, most will cluster in some middle range, with relatively few at the extreme high and low ranges (Galton, 1899). One example is shown in Figure 1.4. Data on height were collected for a national sample of American men from 1971 to 1974. For most of the men, height was between about 168 and 176 cm; relatively few had a height under 160 cm or over 190 cm. The sample approximates a normal distribution, shown in red in the figure. This is sometimes also called a *bell-shaped curve*, or simply a *bell curve*, because of its shape. Knowing that a variable, such as height or memory abilities, follows a normal distribution allows statisticians to make inferences about whether an individual falls within the expected “normal” range or represents an unusually high or low value.

Using his newly developed statistical techniques, Galton sought to assess the efficacy of prayer; in the process, he established many basic statistical methods still used in research today. Galton started with a **hypothesis**, a tentative explanation for an observation, phenomenon, or scientific problem that can be tested by further investigation. He hypothesized that prayer would increase the health and lifespan of the persons being prayed for (Galton, 1872). Galton then proceeded to test this hypothesis by designing a **correlational study**, seeing whether two variables (being prayed for, and health and longevity) tended to vary together: as prayer increased, did health and longevity increase too?

He considered two groups: an **experimental group**, which is a group treated in the manner dictated by the hypothesis, and a **control group**, which is not given any treatment. In Galton's study, the experimental group consisted of people who, he assumed, were the most prayed-for members of society: the ruling monarchs. The control group consisted of nonroyals, both aristocrats and common people. According to Galton's hypothesis, the highly prayed-for monarchs of English history should have lived longer and healthier lives than members of the control group. Galton calculated that the mean age of death of English sovereigns was about 64 years, whereas, on average, members of the aristocracy (other than the ruling monarchs) lived about 67 years, and common people lived even longer—70 years on average. Thus, Galton concluded, not only did prayer not increase longevity, but it seemed to have the opposite effect!

From the perspective of modern research methods, we can ask whether Galton's study was really the best way to test his hypothesis. What if royalty died young because monarchs ate and drank too much and were occasionally assassinated? The problem with Galton's correlational approach was that he was not able to control for the possibility of **confounds**, extraneous variables (such as diet and assassination) that happen to co-vary with the variable (prayer) being examined (of course, his research was also flawed in that he assumed everyone was really praying for the health of the king). Confounds can lead to erroneous assumptions about what is causing an observed result.

Following his seminal contributions to the development of experimental and statistical methods in science, Galton's later years were largely consumed with applying natural selection to the betterment of mankind. Borrowing from the Greek word for "well-born," *eugenes*, Galton introduced the term **eugenics**, a program for encouraging marriage and procreation among the healthiest, strongest, and most intelligent members of society while at the same time discouraging childbearing in the mentally or physically unfit (Galton, 1883). Galton's eugenics movement grew in popularity and respectability during the early 1900s, as people were excited by the prospect of applying Charles Darwin's ideas of natural selection to improve the human condition. Today, however, the eugenics movement is remembered mostly for the disreputable variants it spawned, such as the forced sterilization of mentally ill individuals in California in the 1920s, and for its use during World War II as a rationalization for the mass murder of Jews, Romanies, homosexuals, and other victims of the Nazis. Despite his association with eugenics, Galton's most enduring legacies are his contributions to understanding the role of inheritability in behavioral traits and the development of novel statistical and experimental methods for psychology. Further discussion of the mechanisms by which individual differences in learning and memory abilities are inherited will be discussed in Chapter 9, "Working Memory and Cognitive Control," and Chapter 12, "Development and Aging: Learning and Memory across the Lifespan."

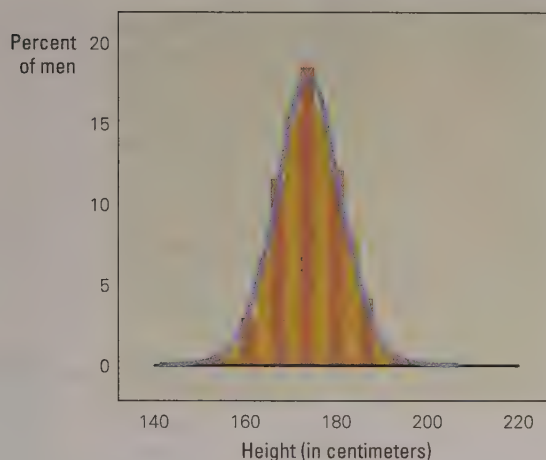


Figure 1.4 A A bell

curve The distribution of variables in the natural world often produces a bell-shaped curve called a normal distribution, with many values in the middle range and few extreme outliers. Here, for example, height data collected between 1971 and 1974 for 4,635 American men show that most values cluster in the middle range, around 168 to 176 cm, with relatively few extremely tall or extremely short outliers. The blue line shows the statistically expected distribution, and the height data mirror this distribution quite well. Adapted from Carl J. Schwarz.

Interim Summary

- Erasmus Darwin and other early proponents of biological evolution believed that species evolve over time, although they did not yet know how or why evolution occurs.

- Charles Darwin's theory of natural selection proposed a mechanism for evolution: survival of the fittest. According to this theory, evolution occurs when one variation of a naturally occurring and inheritable trait gives an organism a survival advantage, making the organism more fit—more likely to survive and reproduce and pass this trait on to its offspring.
- Francis Galton was an avid proponent of the inheritability of behavioral traits. He made fundamental contributions to experimental methods and statistics, including the process of testing hypotheses by comparing two groups: an experimental group (that is subject to the variable of interest) and a control group (that is not).

1.3 The Birth of Experimental Psychology

Most of the scientists and philosophers described to this point in the chapter observed the natural world and derived general principles to explain what they saw. In the late 1800s, an important change took place, inspired by the rigorous work of Galton described earlier. Instead of merely collecting information and looking for correlations, scientists interested in psychology began to follow the lead of physical scientists such as chemists by conducting systematic **experiments**, specific tests to examine the validity of a hypothesis by actively manipulating the variables being investigated, using the approaches and methods Galton had begun to systematize. The testing of psychological theories by experimentation rather than merely by observation of natural occurrences is called **experimental psychology**.

Hermann Ebbinghaus and Human Memory Experiments

Hermann Ebbinghaus (1850–1909), a contemporary of William James, conducted the first rigorous experimental studies of human memory. After earning his PhD, Ebbinghaus lived an itinerant life, traveling, attending occasional seminars, and working for short periods as a teacher and private tutor. One day, browsing at a bookstall, he came across a book by a German physicist, Gustav Fechner (1801–1887), that described the science of human perception. Fechner showed that there are highly predictable regularities in how people perceive variations in physical stimuli, such as changes in the brightness of a light or the

weight of a ball. The book showed how a simple mathematical equation could describe the relationship between the physical world and the psychological world. Captivated by these ideas, Ebbinghaus proposed that the psychology of memory could also become a rigorous natural science, defined by precise mathematical laws.

Unlike many of the scientists discussed in this chapter, Ebbinghaus was not a wealthy man. Unable to afford to pay anyone to participate in his research, he did his studies using himself as the only participant. Despite this limitation, his work laid the foundation for all future experimental studies of human memory; in fact, Ebbinghaus is often considered to be the father of modern memory research.

Ebbinghaus sought mathematical equations to explain how memories are acquired and how they fade. Early on, he realized that if he studied lists of real words, his data would be strongly affected by the fact that he was more familiar with some words than others. To avoid this problem, he used

I Hermann Ebbinghaus



three-letter nonsense words, such as BAP, KEP, and DAK, which would be unfamiliar to him. Ebbinghaus's use of simple, unfamiliar nonsense words was a critical advance in the methodology for studying principles of human memory. In one of his experiments, Ebbinghaus read a list of 20 words out loud to himself, put away the list for a while, then tried to remember as many words as possible. Afterward, he checked which words he missed, reviewed the list, and tried again. He repeated this process until he could remember all 20 words from the original list. This experiment contains the four key stages of a memory experiment—learning, delay, test, relearning—that represented the basic methodology for human memory experiments for years to follow. Further examples of these kinds of studies will be discussed in Chapter 7, “Semantic and Episodic Memory: Memory for Facts and Events.”

Ebbinghaus was especially interested in **forgetting**, that is, in how memory deteriorates over time. He measured forgetting by examining how long it took him to relearn a previously learned list. If it initially took him 10 minutes to learn the list and later took only 6 minutes to relearn the same list, Ebbinghaus recorded a “time savings” of 4 minutes, or 40% of the original learning time. By testing himself at various intervals after learning, Ebbinghaus was able to plot a **retention curve**, which measures how much information is retained at each point in time following learning. Figure 1.5 shows an example of this, graphing the percentage savings in time for relearning the list at various delays between the initial learning and relearning (Ebbinghaus, 1885/1913).

As you can see in Figure 1.5, there is a strong time savings (nearly 100%) if the delay between learning and relearning is short. But as the delay grows longer, to about 100 hours (approximately 4 days), the savings declines to 25%. The retention curve also illustrates that most forgetting occurs early on: if a memory can survive the first few hours after learning, there is little additional forgetting. Thus, Ebbinghaus showed a savings of 25% after 150 hours, and this dropped only to 20% after 750 hours. In other studies, Ebbinghaus showed that shorter lists were easier to remember than longer lists. He also demonstrated that increasing the amount of initial practice improved later recall.

In contrast to Galton's correlational studies of prayer, which examined the effects of prayer as it naturally occurred among members of society, Ebbinghaus designed and conducted experiments in which one variable factor, called the **independent variable**, was carefully manipulated (for example, the length of the delay between learning and relearning), and its effect on the factor under observation, the **dependent variable** (in his experiments, usually memory retention), was carefully measured. Through this design, Ebbinghaus was able to show how changes in the independent variable (e.g., delay length) determine changes in the dependent variable (e.g., memory retention).

The major limitation of Ebbinghaus's studies was that they were conducted with just one participant, Ebbinghaus himself. There are several reasons why such self-experimentation is problematic and would not meet modern scientific standards for research. First, what if Ebbinghaus's memory was different from most other people's? If so, the results of his experiments would tell us a lot about Ebbinghaus but would not be applicable to other people. For this reason, modern research on memory usually involves testing a large number of people.

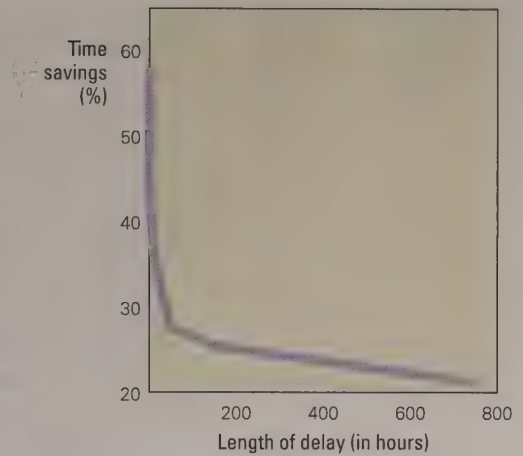


Figure 1.5 Ebbinghaus's retention curve These experimental data show the percentage savings in time for relearning a list of words as a function of the delay between learning and relearning. Ebbinghaus's early study demonstrated that retention drops quickly in the first few days (up to about 100 hours for the task shown here) and then tapers off more slowly with increasing delays. Adapted from Ebbinghaus, 1885/1913.

Test Your Knowledge

Ebbinghaus and Galton's Contributions to Scientific Methodology

The impact of Galton's and Ebbinghaus's contributions to scientific methodology spread far beyond the boundaries of psychology and the study of learning and memory. Some of these contributions are described below. Fill in the blanks with the appropriate term or concept. (Answers appear in the Answers section in the back of the book.)

1. In a correlational study, Galton would distinguish between the _____, who received treatment based on the hypothesized effect of some variable, and the _____, who did not receive such treatment.
2. The ability of an experiment or study to confirm or disconfirm a hypothesis can be undermined by the presence of extraneous variables known as _____.
3. Because Ebbinghaus was both the experimenter and subject in his experiments, his data were potentially compromised by both _____ and _____. In other words, he did not employ a _____ design.

A second problem is that, because he was the experimenter as well as the participant, Ebbinghaus knew which variables were being manipulated. If, for example, he believed that longer lists were harder to learn, then this belief might subtly influence him to take longer to learn those lists. This problem is sometimes called **subject bias**. To avoid such problems, modern studies of memory employ a **blind design**, which means that the participant does not know the hypothesis being tested or the variables being manipulated. There is also a corresponding problem of **experimenter bias**, which means that even a well-meaning experimenter might influence the outcome (for example, by implicitly encouraging the participant to respond in an expected manner). Experimenter bias can be avoided by use of a **double-blind design**, in which neither the participant nor the experimenter knows the hypothesis being tested. A common modern example of the double-blind strategy is its use to test experimental medications. Patients receive either the test drug or a **placebo** (an inactive pill that looks just like the real drug), and neither the patients nor the doctors know who is receiving which kind of pill; only the people analyzing the results (who never interact directly with the research participants) know which is which.

Despite the imperfections in his experimental designs, Ebbinghaus led the way in the use of scientific experimentation to study learning and memory. There are few studies of human memory conducted today that don't owe their methodology to the early and influential work of Hermann Ebbinghaus.

Ivan Pavlov's Conditioning Studies

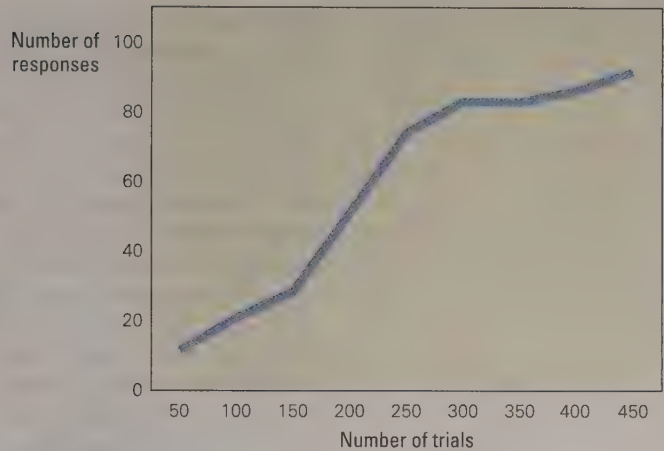
While Ebbinghaus was revolutionizing the study of human memory, the Russian physiologist Ivan Pavlov (1849–1936) was developing methods for studying animal learning that are still in widespread use today. As a young man, Pavlov trained to be a Russian Orthodox priest, like his father and grandfather. In addition to his religious readings, Pavlov read Darwin's recently published *Origin of Species*. Inspired by Darwin's accomplishments,

I Ivan Pavlov





(a)



(b)

Pavlov abandoned his plan to become a priest and enrolled in the school of natural sciences at the University of St. Petersburg. For the rest of his life, Pavlov would acknowledge the enormous impact of Darwin's writings on his own career and thinking.

Although remembered today for his seminal contributions to the psychology of learning, Pavlov's 1904 Nobel Prize in Physiology or Medicine was awarded for his research on the physiology of salivation and digestion in dogs. As described in more detail in Chapter 4, "Classical Conditioning: Learning to Predict Important Events," Pavlov conducted a systematic study of the factors that influence how an animal learns. As illustrated in Figure 1.6a, he inserted surgical tubes (not shown) into the mouths of dogs to collect saliva and could then measure salivation in response to various cues. In one study, he began by training a dog to expect that the sound of a doorbell always preceded delivery of food; over many trials in which the sound of the doorbell was paired with food, the dog developed a stronger and stronger salivation response to the sound of the bell. This form of learning, in which an animal learns that one stimulus (in this case, a doorbell) predicts an upcoming important event (in this case, delivery of food), is known today as **classical conditioning** (or Pavlovian conditioning). Modern studies of classical conditioning usually report the results as a **learning curve**, like that shown in Figure 1.6b, which plots the number of training trials (the independent variable, plotted on the horizontal axis) against the animal's response (the dependent variable, plotted on the vertical axis).

Pavlov's view of how an animal learns a new behavioral response was based on an analogy to what at the time was a new technology that had recently been introduced in Russia: the telephone. As Pavlov explained it, he could call his lab from home via a *direct* private line, which was a fixed connection, much like the fixed connection between food and salivation in a dog's brain. Alternatively, he could call his lab by going through an *indirect* pathway, via a switchboard operator, creating a modifiable connection, much like the newly learned connection between the bell and the dog's salivation (Pavlov, 1927).

In other studies, Pavlov and his assistants showed that they could also *weaken* an animal's trained response to the bell. This was done by first pairing the bell with food, until the animal had learned to salivate to the bell, and then pairing the bell with the absence of food. Pavlov called this process **extinction**: the

Figure 1.6 Pavlov and learning experiments (a) Pavlov (with white beard) and his assistants in the laboratory. A restrained dog has a surgical tube (not shown here) inserted into its mouth to collect and measure salivation in response to meat placed in front of it or to a cue such as a doorbell, which predicts delivery of the food. (b) A learning curve from a modern study of classical conditioning. The curve plots the number of training trials (the independent variable) against the animal's conditioned response (the dependent variable).

salivation to the bell gradually decreased as the animal learned that the bell no longer predicted food.

Pavlov also demonstrated that an animal will transfer what it has learned about one stimulus to similar stimuli. For example, he observed that once an animal learned to respond to a metronome ticking at 90 beats per minute, it also responded to similar sounds, such as a metronome ticking at 80 beats per minute or 100 beats per minute. However, the more dissimilar the new stimulus was to the original stimulus, the less intense was the dog's salivation response. These graded responses to stimuli of varying dissimilarity to the original training stimulus are an example of **generalization**, the ability to transfer past learning to novel events and problems. In Chapter 6, "Generalization and Discrimination Learning," you will see that generalization occurs in many different forms of learning and memory.

Ivan Pavlov lived through the Russian Revolution of 1917, developing a deep animosity toward the new Communist regime (especially after it stole his Nobel Prize money). Nevertheless, when Pavlov died, in 1936, he was given an elaborate funeral with full honors as a hero of the Soviet state.

Edward Thorndike and the Law of Effect

Meanwhile, over in the United States, Edward Thorndike (1874–1949), a student of William James, was studying how animals learn the relationship or connection between a stimulus and a behavioral response that leads to a desirable outcome. Some of Thorndike's most influential studies involved how cats learn to escape from puzzle boxes—cages secured with complex locking (and unlocking) devices. Thorndike called this kind of training, in which organisms learn to make responses in order to obtain or avoid important consequences, **instrumental conditioning**, because the organism's behavior is instrumental in determining whether the consequences occur. This is in contrast, for example, to the learned response (salivation) of Pavlov's dogs, in which the dogs received their food reward regardless of whether or not they made the learned response. Instrumental conditioning, now more commonly referred to as **operant conditioning**, is the focus of Chapter 5, "Operant Conditioning: Learning the Outcome of Behaviors."

I Edward Thorndike



In his studies, Thorndike observed that the probability of a particular behavioral response increased or decreased depending on the consequences that followed. He called this the **law of effect** (Thorndike, 1911). If a particular response led to a desirable consequence, such as access to food, then the probability of the animal making that response in the future *increased*. On the other hand, if the response led to an undesirable consequence (say, an electric shock), then the probability of the animal making that response in the future *decreased*. Fascinated, Thorndike began to methodically investigate the factors that influence how an animal learns new behaviors to maximize its chances of obtaining desirable consequences and avoiding undesirable ones.

Like many psychologists of his era, Thorndike was strongly influenced by Charles Darwin's theory of natural selection. The basic idea of Thorndike's law of effect has much in common with Darwin's principle of survival of the fittest. In Darwin's theory of evolution, variability in traits was key: animals possessing an inherited trait that increases the likelihood of survival pass it on to future generations. Thorndike's law of effect applied the same principle to explain how behaviors evolve during an animal's lifetime. According to the law of effect, an animal has a range of behaviors: those

behaviors that lead to positive consequences for the animal tend to persist; those that do not tend to die out. Starting from this basic principle, Thorndike argued that the psychology of learning should center on the search for the rules describing how, when, and to what degree connections among stimuli and responses are increased or decreased through experience (Thorndike, 1932, 1949).

In 1917, Thorndike became the first psychologist elected to the prestigious U.S. National Academy of Sciences, and in the early 1920s he was often identified as one of the most influential scientists in the United States. He died in 1949, the last of the pioneers in experimental psychology of learning and memory. Thorndike's work set the stage for the next major movement in learning research: the behaviorists of the mid-twentieth century.

Interim Summary

- With the emergence of experimental psychology in the late 1800s, the study of learning and memory, as well as other branches of psychology, began to employ experiments designed to test specific hypotheses. Many of the central figures in this movement were strongly influenced by Charles Darwin's recent work on evolution and natural selection.
- Hermann Ebbinghaus conducted the first rigorous experimental studies of human memory. He introduced the technique of studying lists of short nonsense words and collected data on how information is retained and forgotten.
- Ivan Pavlov discovered a basic method for training animals to associate a previously neutral stimulus, such as a bell, with a naturally significant stimulus, such as food.
- Edward Thorndike showed that the probability of an animal making a behavioral response increases or decreases depending on the consequences that follow. He called this principle the law of effect. It was analogous to Darwin's idea of survival of the fittest: those responses that produce the most beneficial effects survive, while others die out.

Test Your Knowledge

Who's Who in the History of Learning and Memory?

Below is a (slightly tongue-in-cheek) review of the major researchers and ideas covered in the first three sections of this chapter. See if you can fill in the blanks with the names of the researchers. (Answers appear in the Answers section in the back of the book.)

- | | |
|---|--|
| <p>1. Old _____ was a Greek
Who thought about association.
_____, the dualist, liked to speak
Of mind-and-body separation.</p> | <p>4. _____ thought all beasts
Evolved toward perfection.
His grandson proposed the means,
called natural selection.</p> |
| <p>2. To _____, a baby's mind was blank,
As all empiricists have said.
Nativists called him a crank,
Believing knowledge is inbred.</p> | <p>5. _____ now is known
For championing eugenics
But we should also note it down:
He pioneered statistics.</p> |
| <p>3. _____'s models of the mind
Had features linked together,
Updating Greeks from ancient times
And going them one better.</p> | <p>6. _____ learned nonsense words;
Dogs learned to drool for _____.
_____ studied food rewards
(And coined "effect, the law of").</p> |

1.4 The Reign of Behaviorism

In the 1920s, an American approach to learning emerged that was called **behaviorism**. Building on the work of Pavlov and Thorndike, it argued that psychology should restrict itself to the study of observable behaviors (such as lever presses, salivation, and other measurable physical actions) and avoid reference to unobservable, and often ill-defined, internal mental events (such as consciousness, intent, and thought). Proponents of this approach, who were called *behaviorists*, wanted to distance themselves from philosophers and psychologists who explored the inner workings of the mind through personal introspection and anecdotal observation. Behaviorists wanted psychology to be taken seriously as a rigorous branch of natural science, no less solid than biology or chemistry.

John Watson's Behaviorism

Brash, ambitious, and self-made, John Watson (1878–1958) is considered the founder of behaviorism. He was born in Greenville, South Carolina, to a ne'er-do-well father who abandoned the family when Watson was 13 years old. Although a poor student as a child, Watson not only finished college but went on to graduate school, where he conducted research on how rats learn. In these studies, Watson placed a rat at the entrance to a maze and rewarded it with food if it found its way through the corridors to the exit.

Initially, a “naive” (i.e., untrained) rat might spend half an hour wandering randomly through the maze until it reached the exit. After 30 training trials, however, the rat could traverse the maze in less than 10 seconds. To find out what drove the rat's performance, Watson systematically eliminated various possibilities. First, he trained rats to run through the maze under normal conditions. Then he surgically blinded the rats, or rendered them deaf, or removed their whiskers (which rats use like fingertips to feel their way). None of these treatments impaired the rats' performance. Thinking the rats might be using olfactory cues to find their way, Watson boiled the mazes to eliminate all odors. The rats still found their way through.

Only when the maze was rotated or when the corridors were made shorter or longer did the rats show a significant loss in their ability to navigate the maze. From these studies, Watson argued that the rats had learned an automatic set of motor habits for moving through the maze and that these motor habits were largely independent of any external sensory cues (Watson, 1907). Such learned motor habits, or skills, are discussed further in Chapter 8, “Skill Memory: Learning by Doing.”

Watson's experiments were widely admired by his scientific colleagues. Unfortunately, the reception in the popular press was not so enthusiastic. The media described Watson as a cruel torturer of animals, and he was threatened with criminal prosecution (Dewsbury, 1990). When the anti-vivisectionist (pro-animal rights) *Journal of Zoophily* reported, incorrectly, that Watson planned to do similar studies on humans, an even greater outcry ensued. Watson's department chair defended him by pointing out that the surgeries were all done under antiseptic conditions, with the animal anesthetized and with a minimum of pain.

The tension between animal rights activists and psychological researchers continues to this day. In contrast to Watson's era, when there were few constraints on



Underwood & Underwood/Corbis

| John Watson

animal research, studies today are strictly controlled by government agencies and professional organizations to ensure that all experimental animals are handled as humanely as possible. Before any experiment can be conducted, the researchers must seek approval from their institution's ethics board, a committee composed of scientists and lay members of the community, and describe the measures that will be taken to minimize the animals' pain or suffering. Researchers conducting studies on humans are subject to additional ethical scrutiny to ensure protection of participants' rights, privacy, and safety. Only if the ethics board approves the procedures can the research begin. In Watson's day, though, such ethical considerations were left largely to the discretion of the researcher.

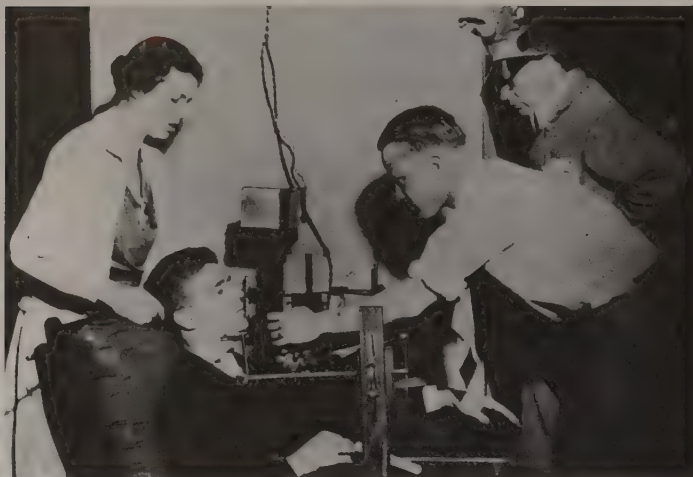
According to Watson, psychology should be viewed as a "purely objective experimental branch of natural science. Its theoretical goal is the prediction and control of behavior" (Watson, 1913). Watson was a strong empiricist, sharing Locke's belief in the overwhelming influence of experience (nurture) versus heredity (nature) in determining our behaviors and capabilities. In a rousing affirmation of Aristotle's principle of the blank slate, Watson wrote: "Give me a dozen healthy infants, well-formed, and my own specified world to bring them up in, and I'll guarantee to take any one at random and train him to become any type of specialist I might select—doctor, lawyer, artist, merchant, chief, and yes even beggarman and thief, regardless of the talents, penchants, tendencies, abilities, vocations, and race of his ancestors" (Watson, 1924, p. 82). In the years following World War I, many people hoped for a new dawn of equal opportunity and freedom from class-based constraints on social progress. Watson's bold claims had a strong appeal for scientists and the wider public. By the early 1920s, behaviorism had become the predominant approach to the psychology of learning, especially in the United States.

Watson's career as an academic researcher came to a sudden end when he became involved in a relationship with his research assistant, Rosalie Rayner. Given Watson's fame as a scientist, his status as a married man, and Rayner's socially prominent family, the affair received intense media scrutiny. In the end, the scandal grew so great that Johns Hopkins University gave Watson a choice between ending his affair or resigning from his position at the university. Choosing to stay with Rayner, Watson resigned from Johns Hopkins and started a successful career in advertising, where he applied the same strict scientific principles to marketing research as to his earlier experiments. In spite of this controversy, the American Psychological Association honored him, soon before his death in 1958, with a gold medal for lifetime contributions to the field of psychology.

Clark Hull and Mathematical Models of Learning

Born on a farm near Akron, Ohio, Clark Hull (1884–1952) devoted his career to developing mathematical equations to describe the relationships among the factors that influence learning. Hull's early life was marked by life-threatening illness. He survived an attack of typhoid fever but sustained lasting brain damage, which caused memory difficulties that plagued him for the rest of his life. He also survived a bout of polio that left him paralyzed in one leg and dependent on crutches to walk.

In Hull's day, the new doctrine of behaviorism claimed that all behavior could be understood as a set of connections between stimuli and responses. When Pavlov's dogs heard the doorbell, they salivated (doorbell → salivation); when Watson's rats entered the maze, they made a series of motor-habit responses (maze entry → turn left, turn right, and so on). Such learning is often called *stimulus-response learning*, abbreviated as *S-R learning*. Of course,



Courtesy of Ernest Hilgard

Clark Hull (standing with visor) and his young graduate student **Ernest Hilgard** (seated) in a study of Pavlovian conditioning at Yale University in the 1920s. Hull trained Hilgard to blink in anticipation of a slap to the face. The slaps did not dissuade Hilgard from going on to a long and productive career in learning research.

the behaviorists acknowledged that the real world is complicated and that other factors might affect the response. For example, Pavlov's dogs might salivate to the doorbell only if they were hungry. Still, the behaviorists believed that if you could specify all the existing factors, you ought to be able to predict exactly whether and when a stimulus would provoke an animal to make a response.

Hull set himself the goal of developing a comprehensive mathematical model of animal learning that would predict exactly what an animal will learn in any given situation. Much as Einstein had recently shown that a single equation, $E = mc^2$, could explain the complex relationship between energy (E), mass (m), and the speed of light (c), Hull hoped to find a similarly powerful equation to relate all the key factors contributing to a learning experience. The variables that Hull entered into his equations included the number of learning trials, the frequency of reward, the spacing between trials, the intensity of the stimulus cues, the animal's motivation for reward, and the incentive value (desirability) of the reward (Hull, 1943). Hull conducted an intensive program of research on learning in animals and humans, seeking to test and refine his mathematical models. One measure of a model's value is its ability to serve as a basis for experimental research; in this regard, Hull's model was a great success. By the 1940s, Hull's work was cited in 70% of all scientific papers on learning published in the major journals (Spence, 1952).

Although Hull's equations were influential in their time, their specifics are no longer considered relevant today. Hull's models have been abandoned because modern psychologists have despaired of ever being able to reduce all the factors governing learning into a single equation, as Hull had hoped to do. Nevertheless, Hull's many students and followers (often called neo-Hullians) carried on toward a smaller goal: to develop mathematical equations to describe basic kinds or components of learning. (You will read in Chapter 4, "Classical Conditioning: Learning to Predict Important Events," about one of the most enduring neo-Hullian learning theories: the Rescorla-Wagner rule, which describes some of the factors governing classical conditioning, like the learning in Pavlov's dogs.) Neo-Hullian researchers showed that learning indeed follows reliable, predictable patterns and pointed the way toward an understanding of how the same basic patterns govern learning in humans as in other animals.

B. F. Skinner's Radical Behaviorism

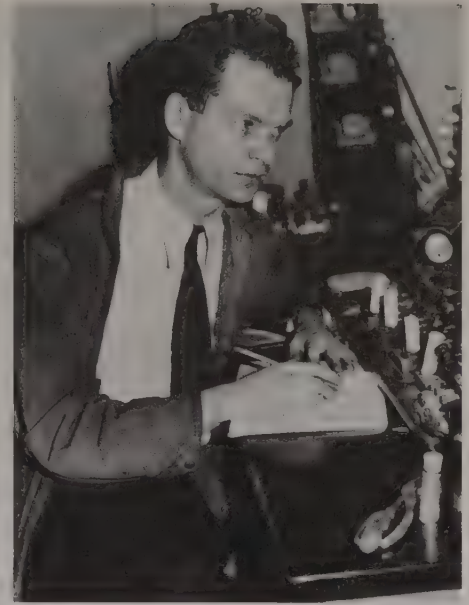
Burrhus Frederic Skinner (1904–1990), born in rural Pennsylvania, became the most famous—and perhaps most infamous—behaviorist of the twentieth century. Although his original goal was to be a writer, Skinner instead went to graduate school in psychology. He placed himself squarely in the behaviorist camp, believing that psychologists should limit themselves to the study of observable behaviors and not try to speculate about what is going on in the mind of an animal while it learns.

In research that extended and refined the techniques Thorndike had developed to study how animals learn new responses, Skinner developed an

automated learning apparatus that was widely adopted by others, who dubbed it the “Skinner box” (you’ll read more about this and Skinner’s other innovations in Chapter 5, “Operant Conditioning: Learning the Outcome of Behaviors”). He also made many important contributions to our understanding of how animals learn the relationship between responses and consequences. One of the most important happened by accident.

In the early 1940s, Skinner was in his laboratory on a Friday afternoon, setting up some studies in which he taught rats to perform a response in order to obtain food pellets. He realized he didn’t have enough food pellets to get him through all the experiments planned for that weekend. Rather than cancel the experiments or go out and get more rat food, Skinner decided to save pellets by providing food only after the rats made two or three correct responses in a row. This led Skinner to one of his greatest discoveries: when trained with intermittent reinforcements, rats learn to respond as quickly and as frequently as when they are rewarded on every trial—in fact, sometimes even better. Skinner and his students began a massive new program of research on how learning is affected by the reliability with which an organism’s responses result in consequences (such as obtaining a food pellet).

Today, B. F. Skinner’s name is far better known than Watson’s or Thorndike’s because his influence extended beyond the laboratory. Fulfilling his early ambition of becoming a writer, Skinner wrote several popular books, including *Walden Two* (1948), which described a highly regulated utopian society in which socially desirable behaviors would be maintained through the same kind of training regimens Skinner applied to his pigeons and rats. In another best-selling book, *Beyond Freedom and Dignity* (1971), Skinner advocated an extreme form of behaviorism, often called **radical behaviorism**, in which he asserted that consciousness and free will are illusions. Humans, like all other animals, he argued, function by blindly producing pre-programmed (learned) responses to environmental stimuli. By the middle of the twentieth century, Skinner was the most famous psychologist in the world. Skinner continued promoting radical behaviorism right up until the night of his death in 1990, which he spent working on a talk for an upcoming convention. The talk was to be titled “Can Psychology Be a Science of the Mind?” (His answer, of course, was a resounding no!) But by that time, mainstream psychology had moved past the strict confines of behaviorism to focus on the very mental events that Skinner and his fellow behaviorists had fought so hard to discredit.



I B. F. Skinner

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The Neo-Behaviorism of Edward Tolman

As a college student at the Massachusetts Institute of Technology (MIT), Edward Tolman (1886–1959) originally planned to pursue a career in chemistry. However, during his senior year he read William James’s *Principles of Psychology* and was so inspired that he decided instead to pursue a graduate degree in psychology.

Tolman began building a series of rat mazes for the study of learning, much as Thorndike and Watson had done before him. In contrast to Watson, who had argued for a purely mechanical approach that described rat learning as the formation of connections between stimuli and responses, Tolman was convinced his rats were learning something more. He believed they had goals and intentions, such as the goal of finding the exit and seeking food. Rats, he argued,



Edward Tolman

are intrinsically motivated to learn the general layout of mazes by forming what he called a **cognitive map**, an internal psychological representation of the spatial layout of the external world (Tolman, 1948). “Behavior reeks of purpose” was Tolman’s well-known and oft-repeated maxim (Tolman, 1932).

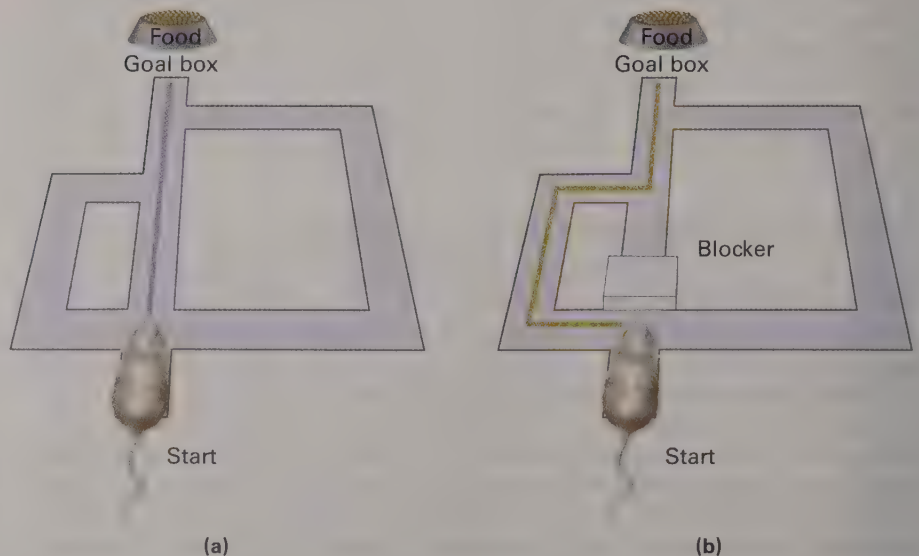
In one series of studies, Tolman showed the value of cognitive maps for understanding how rats can apply what they have learned in novel situations. Rats, he showed, are able to find food in mazes by using alternative routes if their preferred route is blocked, as shown in Figure 1.7 (Tolman, 1948). They can also find their way to the goal if they are started from a novel position in the maze rather than the usual starting point. None of this could be explained by the learning of simple stimulus-response connections.

Tolman even showed that rats can form cognitive maps in the absence of any explicit reward (such as food). He allowed some rats to freely explore a maze (like the one in Figure 1.7), with no food in it, for several days. Later, when he placed these rats in the maze with a food reward at one point (“Goal box”), the rats learned to find the food much faster than rats not previously exposed to the maze and almost as fast as rats that had been explicitly trained to find the food in the

goal box. These studies are described in more detail in Chapter 3, “Habituation, Sensitization, and Familiarization: Learning about Repeated Events” (see especially Figure 3.6). This, Tolman argued, showed that during their free exploration, the rats were learning a cognitive map that they could exploit later. He called this **latent learning**, meaning learning that takes place even when there is no specific motivation to obtain or avoid a specific consequence, such as food or shock (Tolman, 1932). Tolman argued that such latent learning is a natural part of our everyday life. The idea of latent learning challenged a strict

Figure 1.7 Cognitive maps

in rats Tolman believed that rats form cognitive maps, internal representations of the layout of the world. (a) In one experiment, rats placed in a maze (at “Start”) learned to run directly to a box (“Goal box”) where food was provided; the purple line shows the rats’ route. (b) If the preferred route was blocked, rats could easily find an effective alternative route (orange line); this indicates that they had information about the spatial layout of the maze.



behaviorist assumption that all learning reflects stimulus-response associations. Further discussion of the latent learning that results from exposure to places or events can be found in Chapter 3. The effects of latent learning that results from prior exposure to stimuli are discussed both in Chapter 3 and in Chapter 6, “Generalization and Discrimination Learning.”

At a time when Clark Hull and other theorists were seeking to discover fundamental principles of behavior that avoided any mention of unobservable mental events, Tolman took a different approach. Emphasizing the importance of internal representations of the environment and utilizing concepts such as purpose and intent that are not directly observable, only inferred, Tolman broke away from the stricter confines of behaviorist dogma, all the while satisfying the behaviorists’ high standards of experimental control and methodological rigor. For this reason, Tolman is often referred to as a *neo-behaviorist*. His influential theoretical and experimental research—though at odds with many of his behaviorist contemporaries—laid the foundation for cognitive studies of animal and human learning.

Interim Summary

- Behaviorists argue that psychologists should study only observable events and should not attempt to speculate about what’s going on inside an organism. Behaviorism doesn’t deny that internal mental processes exist, just that they are unnecessary and inappropriate subjects for the scientific study of behavior.
- John Watson, the father of behaviorism, proposed that psychology should be a purely experimental branch of natural science whose goal is the prediction and control of behavior in both animals and humans.
- The comprehensive mathematical theories of animal and human learning developed by Clark Hull could be rigorously tested in experimental studies.
- B. F. Skinner conducted detailed studies of the factors that control behavior while at the same time taking the behaviorists’ message to the broader public through widely read and controversial books.
- Edward Tolman, a neo-behaviorist, combined the scientific rigor of the behaviorist methodology with consideration of internal mental events such as goals and cognitive maps of the environment.

1.5 The Cognitive Approach

The behaviorist approach to learning had great appeal. It was rigorous, precise, and amenable to mathematical specification. By avoiding vague and unverifiable suppositions, it offered the promise that psychology would rise in the twentieth century to the status of a serious branch of science, alongside chemistry and physics. However, by the mid-1950s, there was a growing consensus that behaviorism could not, ultimately, deliver a full account of the complexities of human behavior (and probably was insufficient to understand all of animal behavior as well). As you have just read, it failed to account for Tolman’s studies of rats and their cognitive maps. It also failed to explain language, perception, reasoning, and memory, the fundamental components of higher-level human cognition.

Skinner, the radical behaviorist, had argued that language and language acquisition could be explained with behaviorist principles, as a (complex) series of stimulus-response associations (B. F. Skinner, 1957). To counter these claims, linguist Noam Chomsky wrote what may be the most influential book review ever published in the sciences: a critique of Skinner’s book, demonstrating how

and why behaviorist principles alone could not explain how children acquire complex aspects of language such as grammar and syntax (Chomsky, 1959). By the early 1960s, many psychologists interested in human cognition began to turn away from behaviorism, with its focus on animal research and the idea that all learning could be reduced to a series of stimulus-response associations. The stage was set for the rise of **cognitive psychology**, a new subfield of psychology that focused on human abilities such as thinking, language, and reasoning—the abilities not easily explained by a strictly behaviorist approach.



George Estes

I W. K. Estes

W. K. Estes and Mathematical Psychology

William K. Estes (1919–2011) had a long and productive career that encompassed the science of learning and memory from behaviorism to **cognitive science**, the interdisciplinary study of thought, reasoning, and other higher mental functions. Estes, born in 1919, began his graduate studies under the tutelage of Skinner during the early 1940s. As you will read in Chapter 4, “Classical Conditioning: Learning to Predict Important Events,” Estes and Skinner developed a new method for studying classical “Pavlovian” conditioning of fear in rats. Within a few years, their method became one of the most widely used techniques for studying animal conditioning, and it is still in use today. In Chapter 10, “Emotional Influences on Learning and Memory,” you will read that learning about emotions, such as fear, has become an important subfield of learning and memory research.

As soon as he completed his PhD, Estes was called into military service. He was stationed in the Philippines as the commandant of a prisoner-of-war camp—an undemanding job that gave him lots of free time to read the mathematics books his wife sent from home. When the war ended, Estes returned to the United States and to the study of psychology. Much to Skinner’s dismay, Estes soon began to stray from his mentor’s strict behaviorism. He began to use mathematics to describe mental events that could only be inferred indirectly from behavioral data, an approach quite unacceptable to behaviorists. Years later, in his autobiography, Skinner bemoaned the loss of Estes as a once-promising behaviorist, speculating that Estes’s preoccupation with mathematical models of unobservable mental events was a war-related injury, resulting perhaps from too much time in the hot Pacific sun (Skinner, 1979).

Estes built on Hull’s mathematical modeling approach to develop new methods for interpreting a wide variety of learning behaviors (Estes, 1950). Most learning theorists of that era, including Hull, assumed that learning should be viewed as the development of associations between a stimulus and a response. For example, suppose that a pigeon is trained to peck whenever it sees a yellow light, in order to obtain a bit of food. Hull assumed that this training caused the formation of a direct link between the stimulus and the response, so that later presentations of the yellow light evoked the peck-for-food response (Figure 1.8a).

Estes, however, suggested that what seems to be a single stimulus, say a yellow light, is really a collection of many different possible elements making up the yellow light, only a random subset of which are noticed (or “sampled,” in Estes’s terminology) on any given training trial (Figure 1.8b). Only those elements sampled on the current trial are associated with the food. On a different

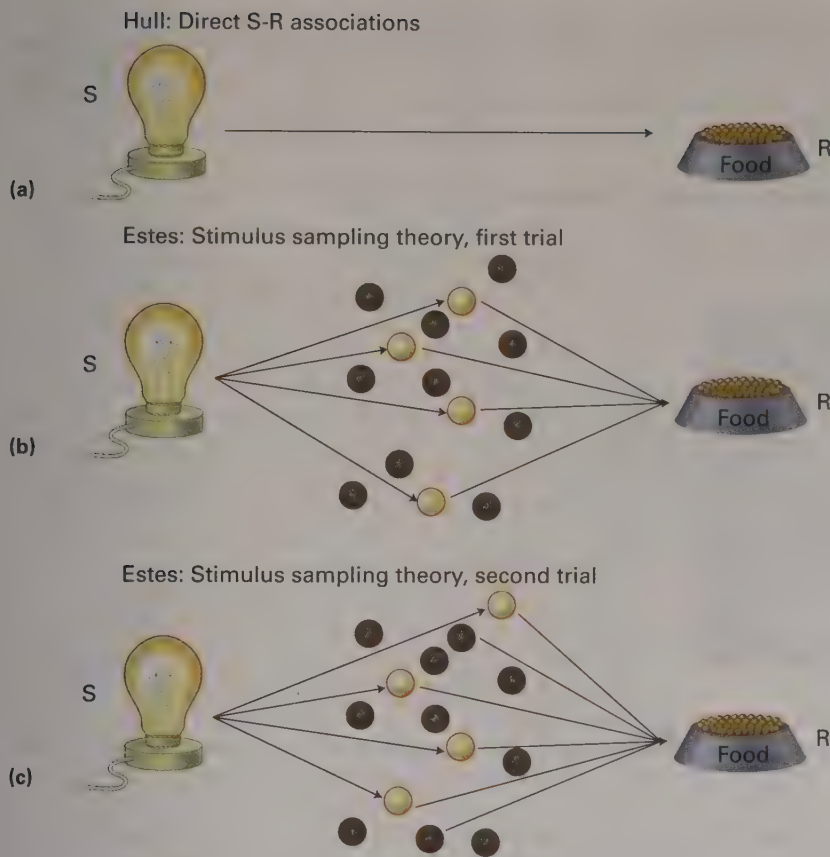


Figure 1.8 Stimulus-response models How does a stimulus (S) become associated with a response (R)? (a) Hull assumed that a direct link was formed between a stimulus (such as a yellow light) and a learned response (such as, in pigeons, pecking for food). (b) Estes proposed an intervening stage, in which a stimulus activates a random sample of elements encoding “yellow”; the activated elements are then associated with the response. (c) On a different trial, a different random subset of elements are activated by the stimulus and associated with the response. Over time, with many such random samples, most elements that could potentially be activated by the stimulus become associated with the response. At this point, when a random sample of elements are activated by presentation of the light, most of them are already linked with the response.

trial, a different subset is sampled (Figure 1.8c), and those elements are now associated with the food. Over time, after many such random samples, most of the elements of the stimulus become associated with the correct response. At this point, any presentation of the light activates a random sample of elements, most of which are already linked with the response.

Estes called his idea *stimulus sampling theory*. A key principle is that random variation (“sampling”) is essential for learning, much as it is essential for the adaptation of species in Charles Darwin’s theory of evolution through natural selection (Estes, 1950). Estes’s approach gave a much better account than other theories (such as Hull’s) of the variability seen in both animal and human learning, and it helped to explain why even highly trained individuals don’t always make the same response perfectly every time: on any given trial, it’s always possible that (through sheer randomness) a subset of elements will be activated that are not yet linked to the response. In Chapter 6, “Generalization and Discrimination Learning,” you will see how Estes’s stimulus sampling theory also explains how animals generalize their learning from one stimulus (e.g., a yellow light) to other, physically similar stimuli (e.g., an orange light), as Pavlov had demonstrated back in the 1920s.

Estes’s work marked the resurgence of mathematical methods in psychology, reviving the spirit of Hull’s earlier efforts. Estes and his colleagues established a new subdiscipline of psychology, **mathematical psychology**, which uses mathematical equations to describe the laws of learning and memory. From his early work in animal conditioning, through his founding role in mathematical

psychology, to his later contributions to cognitive psychology, Estes continued to be a vigorous proponent of mathematical models to inform our understanding of learning and memory. He died in 2011, following a long struggle with Parkinson's disease, a neurological disorder which destroys the brain cells required to learn new habits, and severely impairs movement (see Chapters 5 and 8).

Gordon Bower: Learning by Insight

Gordon Bower was born in 1932 in Scio, Ohio, a small town struggling to survive the Great Depression. Inspired by the movie *The Lou Gehrig Story*, Bower resolved at the age of eight to become a professional baseball player. After playing varsity baseball in college, he had two career choices: professional baseball or graduate school in psychology. Although tempted by the former, Bower figured he had a better chance of long-term success in psychology than in baseball. In graduate school at Yale, Bower got caught up in the heady excitement of mathematical psychology and the efforts of Estes and other mathematical psychologists to describe behavior through mathematical equations.

The dominant psychological learning theories of the time assumed that human learning, like animal learning, proceeded gradually through incremental changes either in association strengths (the Hull approach) or in the statistical probability of a correct response (the Estes approach), both of which predicted gradual transitions in learning performance. In contrast, Bower proposed a new “one-step” model of some human learning. If you’ve ever solved a difficult puzzle or word game, you may have experienced an “aha” moment of insight: Initially, you don’t know the answer; then, all of a sudden, you do know it. Unlike the smooth, incremental learning curves seen in classical conditioning, some learning is experienced as a transition from ignorance to knowledge in a single trial.

Although behaviorists had largely avoided talking about learning by insight, Bower thought it could be explained by a simple mathematical model (Bower, 1961; Bower & Trabasso, 1968). Suppose a person is assigned some task, such as figuring out the sequence in which to press four buttons to open a combination lock. In the beginning, he has no knowledge of the correct answer, but on each trial he will probably try out a different sequence. Odds are that it will take a few trials before he happens to try the correct order. But once he does, and he opens the lock—aha!—he knows the answer. Thereafter, he will press the correct sequence on all subsequent trials. Unlike the smooth learning curve shown in Figure 1.6b, this person’s learning curve would look like the one in Figure 1.9a: a long period of 0% correct responding that transitions all at once into a period of 100% correct responding.

The problem, however, is that most psychologists report *average* learning curves for a group of people, summarizing the data from many participants in the same experiment. Bower’s important insight was that if every participant solves the task in one insightful moment, the trial on which this occurs will vary from one person to another. One participant might learn on the fifth trial, another might get lucky and guess the correct answer on the first or second trial, and someone else might not guess the correct answer until the 15th trial. If a large number of participants are tested, the data will show that almost no one responds correctly on the first or second trial, a few respond correctly on the third or fourth trial, a few more respond correctly on the trials after that,



Courtesy of Gordon Bower

Gordon Bower (seated) and his graduate adviser **Neal Miller** conduct a rat learning experiment at Yale University in the 1950s.

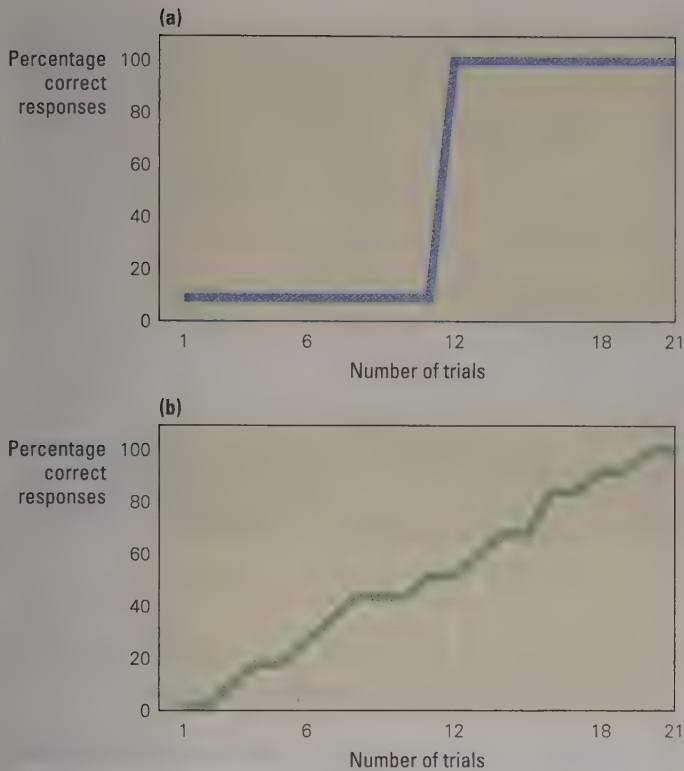


Figure 1.9 Bower's learning by insight If individuals are assigned a task and have no knowledge of the correct answer, they may start off by guessing, stumble across the correct answer, and from then on respond correctly. (a) One participant might guess incorrectly on each of the first 11 trials, making 0% correct responses, and then on trial 12 make the correct response. Thereafter, he continues to give the correct response (100% correct from trial 13 onward). Other participants might make their first correct response on a different trial, but all would show the same basic pattern of an early period of incorrect responding followed by a sharp shift to uniformly correct responding. (b) If individual performances like that in (a) are averaged across many individuals, the result may be a smooth learning curve—even though no single participant showed such incremental learning.

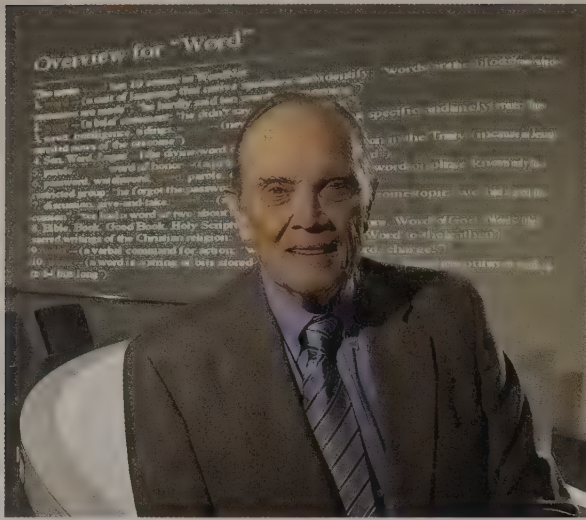
and so on, until, by the end of the experiment, almost everyone is giving the correct response. If we graph the percentage of subjects who give the correct response on each trial of the combination-lock task, the result will look very much like a standard learning curve that moves incrementally from 0 to 100% in the course of the experiment (Figure 1.9b), even though no *individual* participant ever showed incremental learning! By studying such phenomena, Bower showed that to understand learning, it is necessary to consider individual performance, not just averages across a large group of participants. Some other studies that show similar one-trial learning of skills are discussed in Chapter 8, “Skill Memory: Learning by Doing.”

Bower's influence on the field of memory research stems not only from his own research but also from his role as a prolific educator and mentor to young psychologists, many of whom went on to play major roles in the growing field of cognitive psychology.

George Miller and Information Theory

Estes and Bower were not the only investigators becoming disillusioned with the strict confines of the behaviorist approach. Other psychologists too began to seek explanations for observations that could not be explained by the assumption of an incrementally learned association between stimulus and response. One of these was George Miller (1920–2012), another child of the Depression era, who grew up in Charleston, West Virginia.

During World War II, many of Harvard's faculty worked on problems for the military. As a graduate student at Harvard, Miller was given the task of designing a jamming signal to disrupt German radio communications. This wartime research on spoken communications led Miller to study other questions of



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| George Miller

speech perception, such as how context affects communication. For example, if a man floundering in the sea shouts, “Help, I’m drowning!” you might understand the message easily, even if the speech is garbled or indistinct—given the context, it’s obvious what the man is trying to communicate. On the other hand, if you meet the same man on the street, with no prior expectation of what he might be trying to communicate, his speech would need to be much clearer for you to understand the message: is he greeting you, asking for directions, telling you your shoelaces are untied, or soliciting money?

While puzzling over this, Miller read a paper that described *information theory*, a mathematical theory of communication that provides a precise measure of how much information is contained in a message, based not only on the message itself but also on the listener’s prior knowledge (Shannon, 1948). For

example, if a friend tells you that Chris, a student in his psychology class, is male, how much information is in the message? That depends on what you already know. If you already know that all the students in his class are male, then the message contains no new information. If, however, you know that the class is co-ed, information theory would say that your friend’s message contains 1 *bit* of information, where a bit is a “binary digit,” 1 or 0, that can represent two alternative states (such as 1 = female, 0 = male). If you ask your friend about Chris’s gender, all he has to do is reply “1” (female) or “0” (male)—a message composed of a single bit of information is all the answer you need.

Miller’s goal was to adapt information theory to psychology. Specifically, could information theory help us understand how people make judgments about the magnitude of various stimuli? How bright is it? How loud? How high in pitch? Miller discovered that people’s capacity to make judgments concerning magnitude across a range was limited to about seven alternative values (this is why many rating scales ask you to rate your opinions on a scale of 1 to 7, such as a survey that asks you to rate your satisfaction with a new product from 1, not satisfied, to 7, totally satisfied).

At the same time, Miller was conducting a seemingly unrelated project to measure the capacity of people’s short-term memory for digits: he would read aloud strings of numbers and ask people to repeat the numbers from memory. Most people, Miller found, could accurately repeat strings of up to 5 to 9 numbers, but almost no one could remember strings of 10 or more digits. The average memory capacity for numbers (sometimes called a *digit span*) seemed to be about 7 digits, plus or minus 2.

Noting that a capacity of seven appeared in both projects—magnitude rating and digit span—Miller used this seemingly superficial connection as the humorous title of a paper that summarized both projects: “The Magical Number Seven, Plus or Minus Two” (Miller, 1956). The paper became one of the most influential and oft-cited papers in cognitive psychology and spurred later research that showed similar limits on the capacity of human memory for other kinds of information: the “magic number seven” applied not just to digits but to words, pictures, and even complex ideas. Miller’s central message was that the human mind is limited in capacity, that information theory provides a way to measure this capacity, and that these limits apply to a diverse range of human capabilities. Our working memory capacity and capabilities are the focus of Chapter 9, “Working Memory and Cognitive Control.”



The LNR (Lindsay-Normal-Rumelhart) research group at the University of California, San Diego, in the early 1970s with **Peter Lindsay, Donald Norman, and David Rumelhart** in the front row (left to right) holding the flag. The group was at the forefront of research on the symbol-manipulation models of cognition, leading to their book, *Explorations in Cognition*, which applied this framework to perception, language, and memory. Later, Rumelhart grew dissatisfied with the limits of symbolic models and was instrumental in creating more brainlike parallel-distributed processing (PDP) models of cognition.

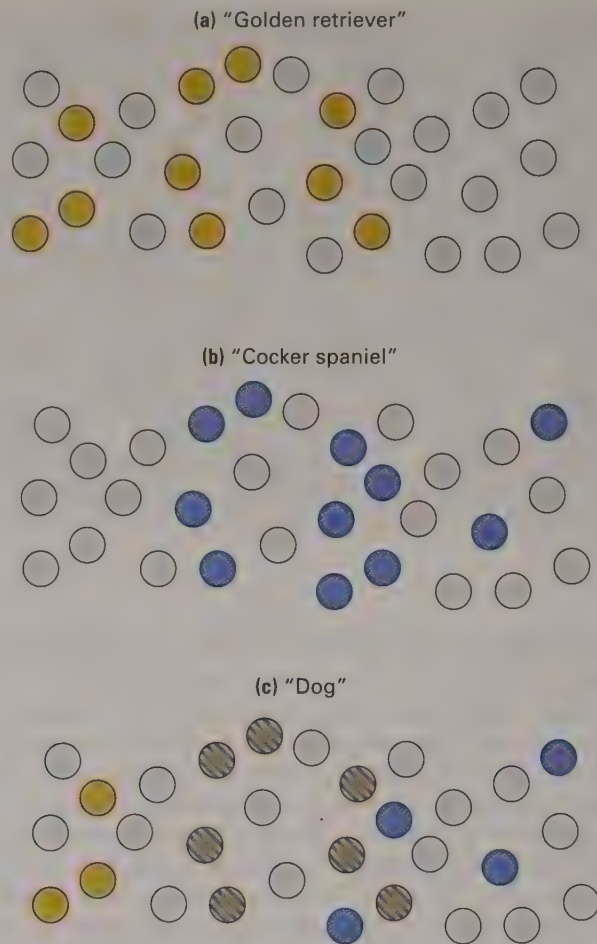
The Connectionist Models of David Rumelhart

David Rumelhart (1942–2011), born in rural South Dakota, was the first of his family to graduate from college. As a graduate student working under Estes, Rumelhart acquired a firm grounding in both psychology and mathematics. He began to apply the tools of mathematics to a wide range of problems in cognition and perception, hoping to improve on the cognitive models in vogue at the time. By the late 1970s, Rumelhart and his colleague James McClelland shared a growing belief that cognition was best understood as networks of connections between simple processing units that in their theory were called *nodes*. Borrowing a term from Thorndike (who had thought much the same), Rumelhart and McClelland called such networks **connectionist models** (Rumelhart & McClelland, 1986).

In connectionist models, ideas and concepts in the external world are not represented as distinct and discrete symbols but rather as patterns of activity over populations of many nodes. In a connectionist model, a golden retriever might be represented by a pattern of activation across a set of nodes (the orange circles in Figure 1.10a). A cocker spaniel might be represented by a different pattern of nodes (blue circles in Figure 1.10b). Such a representation is known as a **distributed representation**, because the information consists of the activation of many different nodes—that is, it is “distributed” across many nodes rather than represented by only one—in a process similar to what Estes had proposed in his stimulus sampling theory. In a connectionist model, the similarity of spaniels to retrievers emerges because they activate common elements—the “dog” elements coded as orange-and-blue circles in Figure 1.10c. The importance of distributed representations and shared elements is discussed in more detail in Chapter 6, “Generalization and Discrimination Learning.”

Connectionist models were inspired in part by ideas about how the brain is organized (see Chapter 2, “The Neuroscience of Learning and Memory”). Part of the expectation held for connectionist models was that they would fulfill William James’s hope for a psychology that links brain physiology to behavior. Connectionist models laid the groundwork for a more complete integration of neuroscience with psychology, a goal that is also a core theme of this book.

Figure 1.10 Distributed representations (a) The representation of “golden retriever” activates one subset of nodes, shown in orange. (b) “Cocker spaniel” activates a different subset, shown in blue. (c) The similarity between them—both are dogs—emerges naturally as a function of the overlap between representations, shown by the orange-and-blue nodes.



After many productive years helping psychologists understand the computational power of networks of brain connections, David Rumelhart's own brain networks began to fail him. In 1998, at the age of 56, he was diagnosed with Pick's disease, an illness (similar to Alzheimer's disease) that causes degeneration of the brain. For the last years of his life, until he died in 2011, he was no longer able to speak or recognize old friends and colleagues. Like Clive Wearing, David Rumelhart lost the vital memories that defined who he was.

Interim Summary

- W. K. Estes built on Hull's mathematical modeling approach to develop new mathematical models for interpreting a wide variety of learning behaviors.
- Gordon Bower developed a simple model of one-trial insight learning that illustrated how individual performance can look quite different from averaged group performance during learning.
- George Miller used information theory to understand memory's limits and mechanisms.
- David Rumelhart played a key role in showing how connectionist network models could link brain processes to the complexities of human memory and cognition.

► SYNTHESIS

At the start of this chapter summarizing the history of the psychology of learning and memory from Aristotle to David Rumelhart, we urged you to notice five themes, or basic questions, interwoven throughout.

1. *How do sensations or ideas become linked in the mind?* Aristotle identified the basic requirements for association more than 2,000 years ago: contiguity, frequency, and similarity. Pavlov showed how we can study and measure learning about associations that exist in the world. Thorndike showed how reward and punishment govern which associations we learn to make. Both Hull and Skinner built on the work of Thorndike, with Hull focusing on mathematical models to explain the factors that influence learning and Skinner expanding the experimental analyses of reward and punishment and applying his research to society. Today, most psychologists take for granted the idea that memory involves forming associations among ideas or sensations, although there are still arguments about exactly how these associations are formed and how they are used.
2. *How are memories built from the components of experience?* Early philosophers and psychologists sought to describe how elements of our experiences could be combined into the whole of consciousness (Locke) or into networks of associations that describe our memories and knowledge (James). Estes's model of memory as distributed patterns of selected elements was updated by Rumelhart and others into connectionist network models that drew inspiration from brain circuits as well as from James's early models of memory.
3. *To what extent are behaviors and abilities determined by biological inheritance (nature) and to what extent by life experiences (nurture)?* Aristotle and Locke firmly believed that we enter the world as blank slates, with our experiences the sole factor influencing our behavior and capabilities. This position, empiricism, carried over into the behaviorism of Watson and Skinner. At the other extreme, Descartes and Galton were more strongly allied with the nature (or nativist) camp and believed that we inherit our talents and abilities. Today, most researchers take the middle road: acknowledging the profound influence of genes (nature) on learning and memory, while noting that a lifetime of experience (nurture) modifies these influences.
4. *In what ways are human learning and memory similar to learning and memory in other animals, and in what ways do they differ?* Most early philosophers assumed that humans were quite distinct from and innately superior to animals, but the proponents of evolution, such as Erasmus and Charles Darwin, showed how similar we are. Behaviorists also emphasized the similarities between animal and human learning, through the study of mechanisms for associative learning that could be demonstrated in several species, including rats, pigeons, and humans. In contrast, the early cognitive psychologists chose to focus on computer-based models of language and abstract reasoning—cognitive behaviors that are not easily studied in nonhuman animals. More recent efforts to reconcile the associationist theories of animal learning and the higher capabilities of human cognition are seen in the connectionist models of Rumelhart, McClelland, and their intellectual descendants. Today, many researchers think of cognition as a continuum, with some animals (e.g., rats and pigeons) perhaps possessing only limited capability for abstract reasoning, but others (e.g., dolphins and

chimpanzees) capable of a degree of communication, reasoning, and use of symbol representation approaching that of humans.

5. *Can the psychological study of the mind meet rigorous scientific standards? If so, might there be universal principles of learning and memory that can be described by mathematical equations and considered fundamental laws?* Throughout the history of studies on learning and memory, philosophers and psychologists have borrowed methods and metaphors from physics, chemistry, and other scientific fields to enhance their understanding. Galton and Ebbinghaus were among the first to show that psychology could indeed be the subject of careful experimentation. Hull attempted to devise mathematical equations to describe learning, and the tradition was continued by Estes and others working in mathematical and cognitive approaches. In current research, most psychologists hold themselves to the same rigorous principles of experimental methodology followed by scientists in other disciplines; if psychologists want their work to be taken seriously, they have to pay close attention to experimental design and analysis.

And . . . what next? In the past few decades there has been a revolution in the field of learning and memory. As you will see in the next chapter, our growing ability to measure and manipulate brain function has fundamentally altered how we look at learning and memory. One consequence of this recent progress has been a fusion of neuroscience and psychology into the integrated study of learning and memory in animals and humans. Despite these recent changes, most current research in the field of learning and memory can be understood as building on the challenges, issues, and questions that have been evolving in philosophy and psychology over the centuries.

Key Terms

associationism, p. 5	dependent variable, p. 17	extinction, p. 19	nativism, p. 5
behaviorism, p. 22	distributed representation, p. 33	forgetting, p. 17	natural selection, p. 13
blind design, p. 18	double-blind design, p. 18	generalization, p. 20	operant conditioning, p. 20
classical conditioning, p. 19	dualism, p. 7	hypothesis, p. 14	placebo, p. 18
cognitive map, p. 26	empiricism, p. 5	independent variable, p. 17	psychology, p. 9
cognitive psychology, p. 28	eugenics, p. 15	instrumental conditioning, p. 20	radical behaviorism, p. 25
cognitive science, p. 28	evolution, p. 12	latent learning, p. 26	reflex arc, p. 7
confound, p. 15	evolutionary psychology, p. 13	law of effect, p. 20	response, p. 7
connectionist models, p. 33	experiment, p. 16	learning, p. 3	retention curve, p. 17
contiguity, p. 5	experimental group, p. 15	learning curve, p. 19	stimulus, p. 7
control group, p. 15	experimental psychology, p. 16	mathematical psychology, p. 29	subject bias, p. 18
correlational study, p. 14	experimenter bias, p. 18	memory, p. 3	theory, p. 4
data, p. 4			

Concept Check

1. If John Watson were to conduct his studies with rats in mazes today, his methods of sensory deprivation would be reviewed by an ethics board. How might he have designed his experiments differently so as to minimize the animals' pain or suffering?
2. Several studies have shown a correlation between the serious mental illness schizophrenia and smoking: people with schizophrenia are more likely than people without schizophrenia to smoke. Does this prove that schizophrenia causes smoking? Explain your answer.
3. Several studies have shown what seems to be a genetic influence on some kinds of memory ability: parents with high memory ability are likely to have children who also have high memory ability. How would an empiricist account for such findings?
4. The 10 tips for better memory in "Learning and Memory in Everyday Life" on page 4 include several that spring directly from principles espoused by associationists (Aristotle, James, and others). Identify these tips and explain your choices.