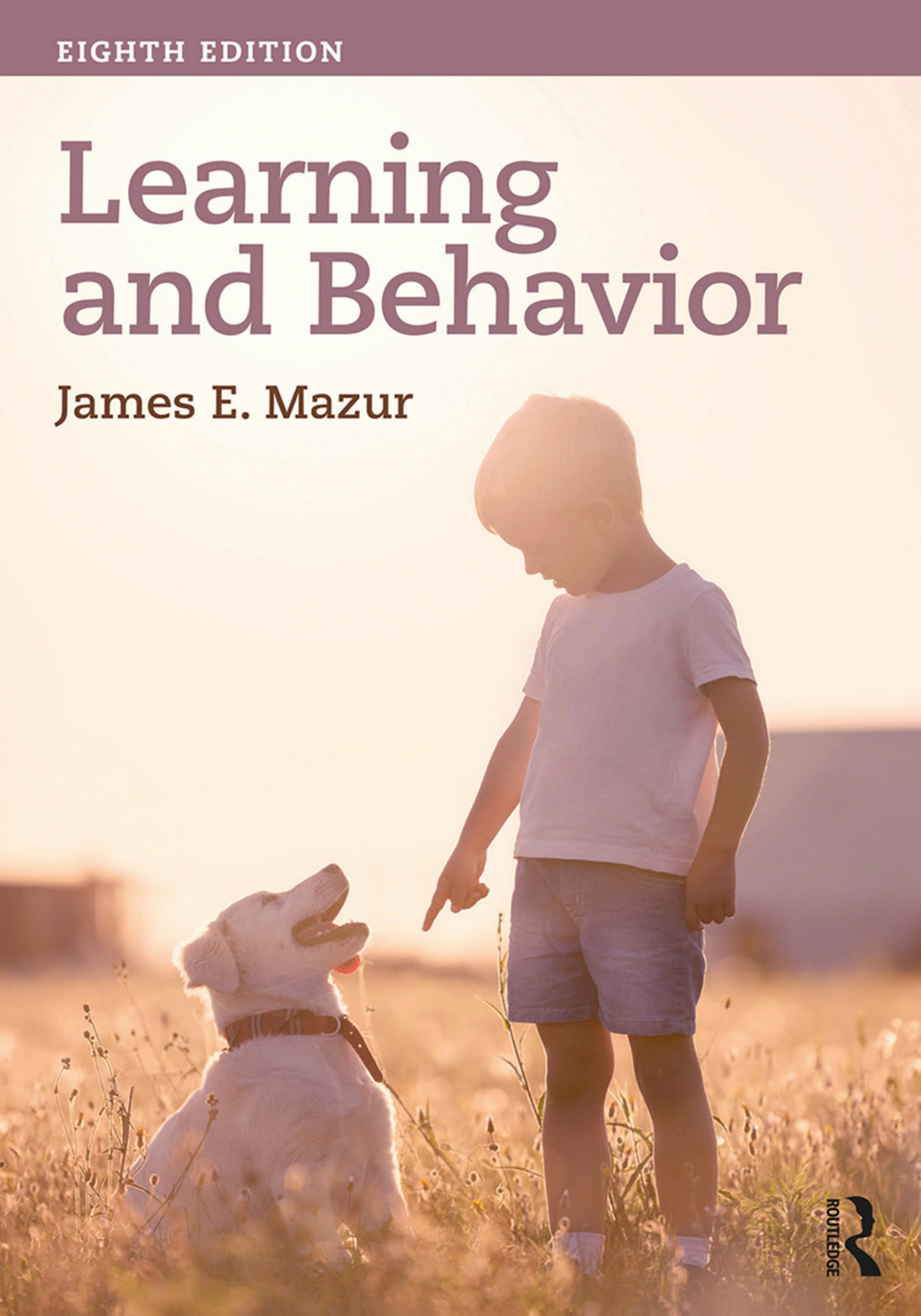
EIGHTH EDITION

Learning and Behavior

James E. Mazur



ROUTLEDGE

Learning and Behavior

This book reviews how people and animals learn and how their behaviors are changed as a result of learning. It describes the most important principles, theories, controversies, and experiments that pertain to learning and behavior that are applicable to diverse species and different learning situations. Both classic studies and recent trends and developments are explored, providing a comprehensive survey of the field. Although the behavioral approach is emphasized, many cognitive theories are covered as well, along with a chapter on comparative cognition. Real-world examples and analogies make the concepts and theories more concrete and relevant to students. In addition, most chapters provide examples of how the principles covered have been applied in behavior modification and therapy. Thoroughly updated, each chapter features many new studies and references that reflect recent developments in the field. Learning objectives, bold-faced key terms, practice quizzes, a chapter summary, review questions, and a glossary are included.

The volume is intended for undergraduate or graduate courses in psychology of learning, (human) learning, introduction to learning, learning processes, animal behavior, (principles of) learning and behavior, conditioning and learning, learning and motivation, experimental analysis of behavior, behaviorism, and behavior analysis.

Highlights of the new edition include:

- A new text design with more illustrations, photos, and tables;
- *In the Media*, *Spotlight on Research*, and *Applying the Research* boxes that highlight recent applications of learning principles in psychology, education, sports, and the workplace;
- Discussions of recent developments in the growing field of neuroscience;
- Coverage of various theoretical perspectives to the study of learning—behavioral, cognitive, and physiological;
- Expanded coverage of emerging topics such as the behavioral economics of addictions, disordered gambling, and impulsivity;
- New examples, references, and research studies to ensure students are introduced to the latest developments in the field;
- A website at www.routledge.com/cw/Mazur where instructors will find a test bank, PowerPoint slides, and Internet links. Students will find practice quizzes, definitions of key terms, chapter outlines, and Internet sources for additional information.

James E. Mazur is Emeritus Professor of Psychology at Southern Connecticut State University, USA.

Learning and Behavior

Eighth Edition

James E. Mazur

Routledge
Taylor & Francis Group
NEW YORK AND LONDON

Eighth edition published 2017
by Routledge
711 Third Avenue, New York, NY 10017

and by Routledge
2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

Routledge is an imprint of the Taylor & Francis Group, an informa business

First edition published 1990 by Prentice-Hall
Seventh edition published 2012 by Taylor & Francis

Library of Congress Cataloging in Publication Data
Names: Mazur, James E., 1951– author.
Title: Learning and behavior / James E. Mazur.
Description: Eighth edition. | New York, NY : Routledge, 2017. |
Includes bibliographical references and index.
Identifiers: LCCN 2016026434 | ISBN 9781138689947 (hardback : alk. paper)
Subjects: LCSH: Learning, Psychology of. | Conditioned response. |
Behavior modification. | Psychology, Comparative.
Classification: LCC BF318 .M38 2017 | DDC 153.1/5—dc23
LC record available at https://lccn.loc.gov/2016026434

ISBN: 978-1-138-68994-7 (hbk)
ISBN: 978-1-315-45028-5 (ebk)

Typeset in Bembo and Helvetica Neue
by Apex CoVantage, LLC

In memory of my parents, Ann and Lou Mazur, who responded to my early interests in science with encouragement, understanding, and patience.

Contents

Detailed Contents

Preface

The purpose of this book is to introduce the reader to the branch of psychology that deals with how people and animals learn and how their behaviors are later changed as a result of this learning. This is a broad topic, for nearly all of our behaviors are influenced by prior learning experiences in some way. Because examples of learning and learned behaviors are so numerous, the goal of most psychologists in this field has been to discover general principles that are applicable to many different species and many different learning situations. What continues to impress and inspire me after many years in this field is that it is indeed possible to make such general statements about learning and behavior. This book describes some of the most important principles, theories, controversies, and experiments that have been produced by this branch of psychology in its first century.

This text is designed to be suitable for introductory or intermediate-level courses in learning, conditioning, or the experimental analysis of behavior. No prior knowledge of psychology is assumed, but the reading may be a bit easier for those who have had a course in introductory psychology. Many of the concepts and theories in this field are fairly abstract, and to make them more concrete and more relevant, I have included many real-world examples and analogies.

Roughly speaking, the book proceeds from the simple to the complex, with respect to both the difficulty of the material and the types of learning that are discussed. Chapter 1 discusses the behavioral approach to learning and contrasts it with the cognitive approach. It also describes some of the earliest theories about the learning process; then it presents some basic findings about the neural mechanisms of learning. Chapter 2 discusses innate behaviors and the simplest type of learning, habituation. Many of the terms and ideas introduced here reappear in later chapters on classical conditioning, operant conditioning, and motor-skills learning. The next two chapters deal with classical conditioning. Chapter 3 begins with basic principles and ends with some therapeutic applications. Chapter 4 describes more recent theoretical developments and experimental findings in this area.

The next three chapters discuss the various facets of operant conditioning: Chapter 5 covers the basic principles and terminology of positive reinforcement, Chapter 6 covers schedules of reinforcement and applications, and Chapter 7 covers negative reinforcement and punishment. Chapters 8 and 9 have a more theoretical orientation. Chapter 8 presents differing views on such fundamental questions as what constitutes a reinforcer and what conditions are necessary for learning to occur. Chapter 9 takes a more thorough look at generalization and discrimination, and it also examines research on concept learning.

Chapter 10 surveys a wide range of findings in the rapidly growing area of comparative cognition. Chapter 11 discusses two types of learning that are given little or no emphasis in

many texts on learning—observational learning and motor-skills learning. A substantial portion of human learning involves either observation or the development of new motor skills. Readers might well be puzzled or disappointed (with some justification) with a text on learning that includes no mention of these topics. Finally, Chapter 12 presents an overview of behavioral research on choice.

This book includes a number of learning aids for students. Each chapter begins with a list of learning objectives and ends with a summary of the main points covered. Each chapter also includes practice quizzes and review questions to help students determine if they are learning and understanding the key points. The book also includes a glossary of all important terms. The website for this text has a number of additional resources. For instructors, there is a test bank of multiple-choice and short-essay questions, PowerPoint slides for use in class, and Internet resources. For students, there are online quizzes for each chapter, definitions of key terms, chapter outlines, and Internet links related to many of the topics covered in the text.

New to this eighth edition are boxes in each chapter that highlight topics that should be of special interest to students. The boxes are focused on three themes: *In the Media*, covering topics related to learning and behavior that have been covered by various media sources, *Spotlight on Research*, taking a closer look at current research on specific topics, and *Applying the Research,* presenting real-world applications of the principles described in the text. This edition also includes many new figures and illustrations to help students understand and remember important concepts, principles, experimental procedures, and applications. To enhance the relevance of this material for today's students, a number of older and somewhat technical topics from previous editions have been removed, and there are more examples of how behavioral and cognitive principles of learning can be observed in people's everyday behaviors. Most of the chapters include sections that describe how the theories and principles of learning have been used in the applied field of behavior modification.

I owe thanks to many people for the help they have given me as I wrote this book. Many of my thoughts about learning and about psychology in general were shaped by my discussions with the late Richard Herrnstein—my teacher, advisor, and friend. I am most grateful to Debra Riegert and Rachel Severinovsky of Taylor and Francis for all the advice and assistance they provided me throughout the work on this edition. Thanks go to the reviewers of various editions of this book:

Matthew C. Bell, Mark Branch, Thomas Brown, Maureen Bullock, Gary Brosvic, Valerie Farmer-Dougan, April Fugett, Adam Goodie, Kenneth P. Hillner, Peter Holland, Ann Kelley, Melinda Leonard, Kathleen McCartney, Harold L. Miller, Jr., David Mostofsky, Thomas Moye, Jack Nation, Erin Rasmussen, David Schaal, James R. Sutterer, Edward Wasserman, Steve Weinert, and Joseph Wister. In addition, I thank Marge Averill, Stan Averill, John Bailey, Chris Berry, Paul Carroll, David Coe, David Cook, Susan Herrnstein, Margaret Makepeace, Margaret Nygren, Steven Pratt, and James Roach for their competent and cheerful help on different editions of this book. Finally, I thank my wife, Laurie Averill, who drew many of the illustrations and gave me plenty of valuable help on this and previous editions.

J. E. M.

About the Author

James E. Mazur obtained his B.A. in Psychology from Dartmouth College in 1973 and his Ph.D. in Experimental Psychology from Harvard University in 1977. He taught at Harvard as an assistant professor and associate professor from 1980 to 1988, and since then he has taught at Southern Connecticut State University, where he was honored with the title of CSU Professor in 2010. He is now Professor Emeritus and continues to teach part-time. He has conducted research on operant conditioning and choice for over 40 years. He has been a reviewer and associate editor for several journals, and he served as editor for the *Journal of the Experimental Analysis of Behavior.* He has published numerous journal articles and chapters on such topics as reinforcement schedules, conditioned reinforcement, self-control, risk taking, procrastination, and mathematical models of choice.

CHAPTER 1

History, Background, and Basic Concepts

Learning Objectives

After reading this chapter, you should be able to

- describe the early theories of memory proposed by the Associationists and the early memory studies of Hermann Ebbinghaus
- explain the behavioral and cognitive approaches to studying learning and how they differ
- explain the advantages and disadvantages of using animals in psychological research
- discuss intervening variables and the debate over whether they should be used in psychology
- explain how our sensory receptors respond to "simple sensations" and how feature detectors in the visual system respond to more complex patterns
- list three main types of changes that can take place in the brain as a result of a learning experience, and present evidence for each type

If you know nothing about the branch of psychology called *learning*, you may have some misconceptions about the scope of this field. I can recall browsing through the course catalog as a college freshman and coming across a course offered by the Department of Psychology with the succinct title "Learning." Without bothering to read the course description, I wondered about the contents of this course. Learning, I reasoned, is primarily the occupation of students. Would this course teach students better study habits, better reading, and better note-taking skills? Or did the course examine learning in children, covering such topics as the best ways to teach a child to read, to write, to do arithmetic? Did it deal with children

who have learning disabilities? It was difficult to imagine spending an entire semester on these topics, which sounded fairly narrow and specialized for an introductory-level course.

My conception of the psychology of learning was wrong in several respects. First, a psychology course emphasizing learning in the classroom would probably have a title such as "Educational Psychology" rather than "Learning." My second error was the assumption that the psychology of learning is a narrow field. A moment's reflection reveals that students do not have a monopoly on learning. Children learn a great deal before ever entering a classroom, and adults must continue to adapt to an ever-changing environment. Because learning occurs at all ages, the psychological discipline of learning places no special emphasis on classroom learning. Furthermore, since the human being is only one of thousands of species on this planet that have the capacity to learn, the psychological discipline of learning is by no means restricted to the study of human beings. For reasons to be explained, a large percentage of all psychological experiments on learning have used nonhuman subjects. Though they may have their faults, psychologists in the field of learning are not chauvinistic about the human species.

Although even specialists have difficulty defining the term *learning* precisely, most would agree that it is a process of change that occurs as a result of an individual's experience. Psychologists who study learning are interested in this process wherever it occurs—in adults, school children, other mammals, reptiles, and even insects. This may sound like a large subject, but the field of learning is even broader than this because psychologists study not only the *process* of learning but also the *product* of learning—the long-term changes in one's behavior that result from a learning experience.

An example may help to clarify the distinction between process and product. Suppose you glance out the window and see a raccoon near some garbage cans in the backyard. As you watch, the raccoon gradually manages to knock over a garbage can, remove the lid, and tear open the garbage bag inside. If we wanted to study this raccoon's behavior, many different questions would probably come to mind. Some questions might deal with the learning process itself: Did the animal open the can purely by accident, or was it guided by some "plan of action"? What factors determine how long the raccoon will persist in manipulating the garbage can if it is not immediately successful in obtaining something to eat? These questions deal with what might be called the **acquisition** phase, or the period in which the animal is acquiring a new skill.

Once the raccoon has become skillful at opening garbage cans, we can ask questions about its long-term performance. How frequently will the raccoon visit a given backyard, and how will the animal's success or failure affect the frequency of its visits? Will its visits occur at the most advantageous times of the day or week? Such questions concern the end product of the learning process, the raccoon's new behavior patterns. This text is entitled *Learning and Behavior*, rather than simply *Learning*, to reflect the fact that the psychology of learning encompasses both the acquisition process and the long-term behavior that results.

THE SEARCH FOR GENERAL PRINCIPLES OF LEARNING

Because the psychology of learning deals with all types of learning and learned behaviors in all types of creatures, its scope is broad indeed. Think, for a moment, of the different behaviors you performed in the first hour or two after rising this morning. How many of

those behaviors would not have been possible without prior learning? In most cases, the decision is easy to make. Getting dressed, washing your face, making your bed, and going to the dining room for breakfast are all examples of behaviors that depend mostly or entirely on previous learning experiences. The behavior of eating breakfast depends on several different types of learning, including the selection of appropriate types and quantities of food, the proper use of utensils, and the development of coordinated hand, eye, and mouth movements. It is hard to think of human behaviors that do not depend on prior learning.

Considering all of the behaviors of humans and other creatures that involve learning, the scope of this branch of psychology may seem hopelessly broad. How can any single discipline hope to make any useful statements about all these different instances of learning? It would make no sense to study, one by one, every different example of learning that a person might come across, and this is not the approach of most researchers who study learning. Instead, their strategy has been to select a relatively small number of learning situations, study them in detail, and then try to generalize from these situations to other instances of learning. Therefore, the goal of much of the research on learning has been to develop general principles that are applicable across a wide range of species and learning situations.

B. F. Skinner, one of the most influential figures in the history of psychology, made his belief in this strategy explicit in his first major work, *The Behavior of Organisms* (1938). In his initial studies, Skinner chose white rats as subjects and lever pressing as a response. An individual rat would be placed in a small experimental chamber containing little more than a lever and a tray into which food was occasionally presented after the rat pressed the lever. A modern version of such a chamber is shown in Figure 1.1. In studying the behavior of

Figure 1.1 An experimental chamber in which a rat can receive food pellets by pressing a lever.

rats in such a sparse environment, Skinner felt that he could discover principles that govern the behavior of many animals, including human beings, in the more complex environments found outside the psychological laboratory. The work of Skinner and his students will be examined in depth beginning in Chapter 5, so you will have the opportunity to decide for yourself whether Skinner's strategy has proven to be successful.

Attempts to discover principles or laws with wide applicability are a part of most scientific endeavors. For example, a general principle in physics is the law of gravity, which predicts, among other things, the distance a freely falling object will drop in a given period of time. If an object starts from a stationary position and falls for t seconds, the equation $d = 16t^2$ predicts the distance (in feet) that the object will fall. The law of gravity is certainly a general principle because in theory it applies to any falling object, whether a rock, a baseball, or a skydiver. Nevertheless, the law of gravity has its limitations. As with most scientific principles, it is applicable only when certain criteria are met. Two restrictions on the equation are that it applies (1) only to objects close to the earth's surface and (2) only as long as no other force, such as air resistance, plays a role. Therefore, the law of gravity can be more accurately studied in the laboratory, where the role of air resistance can be minimized through the use of a vacuum chamber. For similar reasons, principles of learning and behavior are often best studied in a laboratory environment. Every chapter in this book will introduce several new principles of learning and behavior, nearly all of which have been investigated in laboratory settings. To demonstrate that these principles have applicability to more natural settings, each chapter will also describe real-world situations in which these principles play an important role.

Within the field of psychology, researchers have studied the topic of learning in several different ways. The remainder of this chapter gives an overview of these different approaches, plus a brief history of the field and some background information that will help you to understand the topics covered in later chapters. We will begin with some of the earliest recorded thoughts about learning and memory, and then we will examine and compare two modern approaches to learning—the behavioral and cognitive approaches. Finally, this chapter will introduce a third approach to studying learning—the neuroscience approach—which examines what happens in the brain and in individual nerve cells when we learn.

THE ASSOCIATIONISTS

Aristotle

The Greek philosopher Aristotle (c. 350 B.C.) is generally acknowledged to be the first **Associationist**. He proposed three principles of association that can be viewed as an elementary theory of memory. Aristotle suggested that these principles describe how one thought leads to another. Before reading about Aristotle's principles, you can try something Aristotle never did: You can conduct a simple experiment to test these principles. Before reading further, take a few moments to try the demonstration in Box 1.1.

Aristotle's first principle of association was **contiguity**: The more closely together (contiguous) in space or time two items occur, the more likely will the thought of one item lead to the thought of the other. For example, the response *chair* to the word *table* illustrates association by spatial contiguity since the two items are often found close together. The

BOX 1.1 APPLYING THE RESEARCH

A Demonstration of Free Association

This exercise, which should take only a minute or two, can be called a study of free association. Take a piece of paper and a pencil, and write numbers 1 through 12 in a column down the left side of the paper. Below is a list of words also numbered 1 through 12. Reading one word at a time, write down the first one or two words that come to mind.

1. apple
2. night
3. thunder
4. bread
5. chair
6. bat
7. girl
8. dentist
9. quiet
10. sunset
11. elephant
12. blue

Once you have your list of responses to the 12 words, look over your answers and try to develop some rules that describe how you came up with your responses. Can you guess any of Aristotle's three principles?

response *lightning* to the word *thunder* is an example of association by temporal contiguity. Other examples of association by contiguity are *bread-butter* and *dentist-pain*.

Aristotle's other two principles of association were **similarity** and **contrast**. He stated that the thought of one concept often leads to the thought of similar concepts. Examples of association by similarity are *apple-orange* or *blue-green*. By the principle of contrast, Aristotle meant that an item often leads to the thought of its opposite (e.g., *night-day*, *girl-boy*, *sunset-sunrise*). Most people who try this simple free-association experiment conclude that Aristotle's principles of association have both strengths and weaknesses. His list of factors that affect the train of thought seems incomplete, but it is not bad as a first step in the development of a theory about the relationship between experience and memory.

The British Associationists: Simple and Complex Ideas

For some philosophers who wrote about Associationism several centuries after Aristotle, this topic assumed a much greater significance: Associationism was seen as a theory of all knowledge. The **British Associationists** included John Locke (1690), James Mill (1829), and

John Stuart Mill (1843). These writers are also called Empiricists because of their belief that every person acquires all knowledge empirically, that is, through experience. This viewpoint is typified by John Locke's statement that the mind of a newborn child is a *tabula rasa* (a blank slate) onto which experiences make their marks. The Empiricists believed that every memory, every idea, and every concept a person has is based on previous experiences.

The opposite of **Empiricism** is **Nativism**, or the position that some ideas are innate and do not depend on an individual's past experience. For instance, Immanuel Kant (1781) believed that the concepts of space and time are inborn and that through experience new concepts are built on the foundation of these original, innate concepts. As we will see many times throughout this book, modern research has uncovered numerous examples that support Nativism and contradict the extreme Empiricist position that all knowledge is learned through experience. Nevertheless, we can grant that some concepts are innate, but many concepts are developed through experience.

The British Empiricists offered some hypotheses both about how old concepts become associated in memory and about how new concepts are formed. According to the Associationists, there is a direct correspondence between experience and memory. Experience consists of sensations, and memory consists of ideas. Furthermore, any sensory experience can be broken down into simple sensations. For instance, if a person observes a red box-shaped object, this might be broken down into two simple sensations: *red* and *rectangular*. Later, the person's memory of this experience would consist of the two corresponding simple ideas of *red* and *rectangular* (see Figure 1.2a). A simple idea was said to be a sort of faint replica of the simple sensation from which it arose.

Now suppose that the person repeatedly encounters such a red box-shaped object. Through the principle of contiguity, an association should develop between the ideas of *red* and *rectangle*, as shown in Figure 1.2b. Once such an association is formed, if the person experiences the color red, this will not only invoke the idea of red, but by virtue of the association the idea of rectangular will be invoked as well (Figure 1.2c).

Of course, the Associationists realized that many of our concepts are more complex than the simple ideas of *red*, *rectangular*, *thunder*, and *lightning*. In an attempt to come to grips with the full range of memories and knowledge that all people have, some Associationists speculated about the formation of complex ideas. James Mill (1829) proposed that if two or more simple sensations are repeatedly presented together, a product of their union may be a **complex idea**. For instance, if the sensations *red* and *rectangular* occur together repeatedly, a new, complex idea of *brick* may form. Figure 1.2d shows one way to depict Mill's hypothesis graphically. Once such a complex idea is formed, it can also be evoked by the process of association when the sensation of either *red* or *rectangle* occurs. Mill went on to say that complex ideas could themselves combine to form larger **duplex ideas**. In the following passage, Mill (1829) describes the formation of a hierarchy of ideas of increasing complexity:

> Some of the most familiar objects with which we are acquainted furnish instances of these unions of complex and duplex ideas. Brick is one complex idea, mortar is another complex idea; these ideas, with ideas of position and quantity, compose my idea of a wall. . . . In the same manner my complex idea of glass, and wood, and others, compose my duplex idea of a window; and these duplex ideas, united together, compose my idea of a house, which is made up of various duplex ideas.
>
> (pp. 114–116)

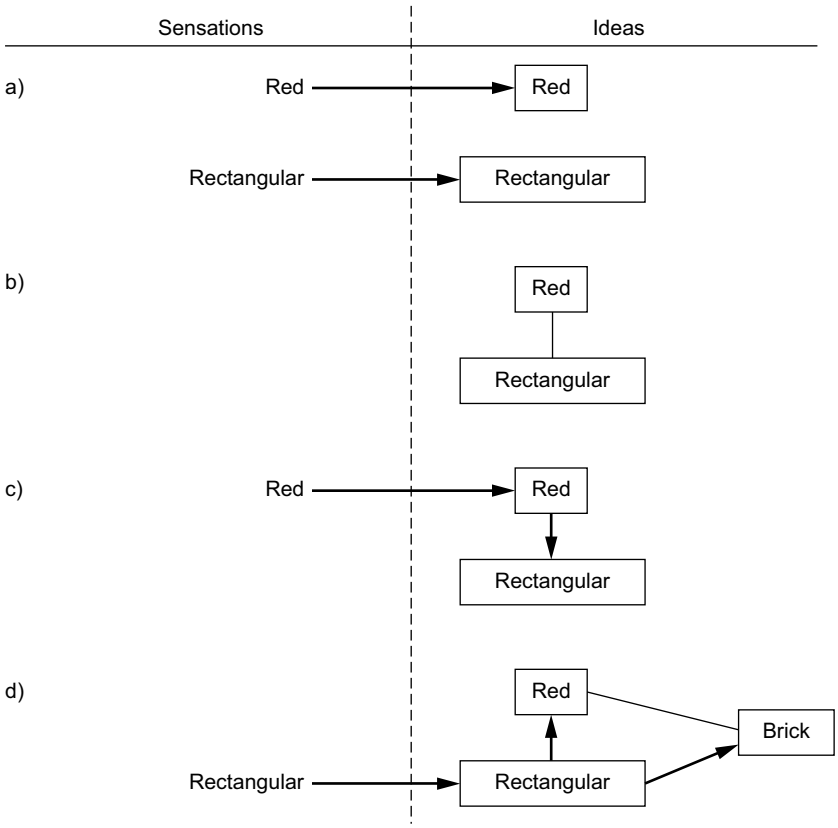


Figure 1.2 Some principles of Associationism. (a) One-to-one correspondence between simple sensations and simple ideas. (b) After repeated pairings of the two sensations, an association forms between their respective ideas. (c) Once an association is formed, presenting one stimulus will activate the ideas of both. (d) With enough pairings of two simple ideas, a complex idea encompassing both simple ideas is formed. The complex idea may now be evoked if either of the simple stimuli is presented.

There are both strengths and weaknesses in this hypothesis. Some types of learning do seem to progress from simple to complex concepts. For example, only after children understand the concepts of *addition* and *repetition* are they taught the more complex concept of *multiplication*, and it is often introduced as a procedure for performing repeated additions. However, other concepts do not seem to follow as nicely from Mill's theory, including his own example of the concept of *house*. A 2-year-old may know the word *house* and use it appropriately without knowing the "simpler" concepts of *mortar*, *ceiling*, or *rafter*. With *house* and many other complex concepts, people seem to develop at least a crude idea of the entire concept before learning all of the components of the concept, although according to Mill's theory this should not be possible. Thus, although it appears to have validity in some cases, Mill's theory is at best incomplete.

Another Associationist, Thomas Brown (1820), tried to expand Aristotle's list by adding some additional principles. For example, he proposed that the *length of time* two sensations

coexist determines the strength of the association, and the *liveliness* or vividness of the sensations also affects the strength of the association. According to Brown, intense stimuli or emotional events will be more easily associated and better remembered. He also proposed that a stronger association will also occur if the two sensations have been paired *frequently* or if they have been paired *recently.*

The ideas of the Associationists can be called the earliest theories of learning, for they attempted to explain how people change as a result of their experiences. However, the Associationists never conducted any experiments to test their ideas. In retrospect, it is remarkable that despite an interest in principles of learning spanning some 2,000 years, no systematic experiments on learning were conducted until the end of the nineteenth century. This absence of research of learning was not a result of technological deficiencies because the first experiments on learning were so simple that they could have been performed centuries earlier.

Ebbinghaus's Experiments on Memory

Hermann Ebbinghaus (1885) was the first to put the Associationists' principles to an experimental test. In his memory experiments, Ebbinghaus served as his own subject. This is not an acceptable arrangement by modern standards because his performance could have been biased by his expectations. Yet despite this potential problem, all of his major findings have been replicated by later researchers using modern research procedures.

To avoid using stimuli that had preexisting associations (such as *coffee-hot*), Ebbinghaus invented the *nonsense syllable*—a meaningless syllable consisting of two consonants separated by a vowel (e.g., HAQ, PIF, ZOD). He would read a list of nonsense syllables out loud at a steady pace, over and over. Periodically, he would test his memory by trying to recite the list by heart, and he would record the number of repetitions needed for one perfect recitation. He then might allow some time to pass and then try to learn the list to perfection a second time, again recording how many repetitions were needed. He could then calculate his *savings*—the decrease in the number of repetitions needed to relearn the list. For example, if he needed 20 repetitions to learn a list the first time, but only 15 repetitions to relearn the list at a later time, this was a savings of 5 repetitions, or 25%.

A few examples will show how Ebbinghaus tested the Associationists' principles. One of Thomas Brown's principles was that the frequency of pairings affects the strength of an association. Obviously, this principle is supported by the simple fact that with enough repetitions Ebbinghaus could learn even long lists of nonsense syllables. However, one of Ebbinghaus's findings provided additional support for the frequency principle. If he continued to study a list beyond the point of one perfect recitation (e.g., for an additional 10 or 20 repetitions), his savings after 24 hours increased substantially. In other words, even after he appeared to have perfectly mastered a list, additional study produced better performance in a delayed test. Continuing to practice after performance is apparently perfect is called **overlearning**, and Ebbinghaus demonstrated that Brown's principle of frequency applies to periods of overlearning as well as to periods in which there is visible improvement during practice.

Another of Thomas Brown's principles was recency: The more recently two items have been paired, the stronger will be the association between them. Ebbinghaus tested this principle by varying the length of time that elapsed between his study and test periods. As shown

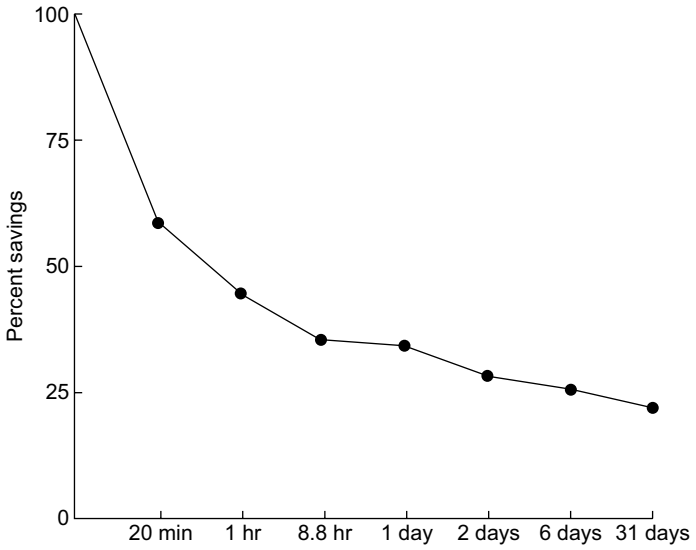


Figure 1.3 Ebbinghaus's forgetting curve. The percentage savings is shown for various time intervals between his initial learning and relearning of lists of nonsense syllables. (After Ebbinghaus, 1885)

in Figure 1.3, he examined intervals as short as 20 minutes and as long as 1 month. This graph is an example of a **forgetting curve**, for it shows how the passage of time has a detrimental effect on performance in a memory task. The curve shows that forgetting is rapid immediately after a study period, but the rate of additional forgetting slows as more time passes. The shape of this curve is similar to the forgetting curves obtained by later researchers in numerous experiments with both humans and animals, although the time scale on the x-axis varies greatly, depending on the nature of the task and the species of the subjects. Forgetting curves of this type provide strong confirmation of Brown's principle of recency.

A final example will show how Ebbinghaus tested Aristotle's principle of contiguity. He reasoned the strongest associations in his lists should be between adjacent syllables, but there should also be measurable (though weaker) associations between nonadjacent items. He devised an ingenious method for testing this idea, which involved rearranging the items in a list after they were memorized and then learning the rearranged list. His technique is illustrated in Table 1.1.

The designations I1 through I16 refer to the 16 items as they were ordered in the original list (List 0). Once this list is memorized, there should be a strong association between I1 and I2, a somewhat weaker association between I1 and I3 (since these were separated by one item in the original list), a still weaker association between I1 and I4, and so on. There should be similar gradations in strength of association between every other item and its neighbors.

The rearranged list, called List 1 in Table 1.1, was used to test for associations between items one syllable apart. Notice that every adjacent item in List 1 was separated by one syllable in the original list. If there is any association between I1 and I3, between I3 and I5, and so on, then List 1 should be easier to learn than a totally new list. In a similar fashion, List 2