
SEVENTH EDITION
THE PRINCIPLES OF LEARNING AND BEHAVIOR
7
MICHAEL DOMJAN

# The Principles of Learning and Behavior

**SEVENTH EDITION**

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*University of Texas at Austin*

*with neuroscience contributions by*
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*Texas A & M University*

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# Dedication

*to Deborah*

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# Boxes on the Neuroscience of Learning

# Preface

Originally, I had three basic goals in writing this book. First, I wanted to share with students the new ideas and findings that made me excited about conditioning and learning. Second, I wanted to emphasize that learning procedures do not operate in a vacuum but are built on behavior systems shaped by evolution. This belief provided the rationale for including *behavior* in the title of the book. Third, I wanted to provide an eclectic and balanced account of the field that was respectful of both the Pavlovian associationist tradition and the Skinnerian behavior-analytic tradition. I have remained faithful to these goals and sought to satisfy them in the seventh edition while being responsive to the ever-changing landscape of research on learning mechanisms.

Although the field of conditioning and learning dates back more than a century (during which some of our technical vocabulary has not changed much), the field continues to be enriched by numerous new phenomena and new interpretations. Recent national priorities for the pursuit of translational research have encouraged a great deal of new research on mechanisms of learning related to drug addiction, fear conditioning, and extinction. One of the interesting new developments is a greater respect for individual differences, which is now informing our understanding of some of the fundamental phenomena of Pavlovian conditioning, as well as punishment and choice behavior, among other topics. Incorporating new developments in the book required judgments about what was important enough to add and what material could be omitted to make room for the new information. Adding things is easy. Removing information that was previously deemed important is more painful but necessary to keep the book to a reasonable length.

A continuing challenge for the book has been how to represent the major advances that are being made in studies of the neuroscience of learning and memory. Unfortunately, a single course cannot do justice to both the basic behavioral mechanisms of learning and the neural mechanisms of these behavioral phenomena. I remain committed to the proposition that one cannot study the neural mechanisms of a behavioral phenomenon without first understanding that phenomenon at the behavioral level of analysis. Therefore, the book continues to be primarily concerned with behavioral phenomena. However, the seventh edition includes more information about the neuroscience of learning and memory than any previous edition.

As in the sixth edition, most of the neuroscience information is presented in boxes that can be omitted by instructors and students who do not wish to cover this material. I am grateful to James W. Grau, Professor of Psychology and Neuroscience at Texas A&M University, for writing the "neuroboxes." The seventh edition includes a neurobox in each chapter of the book. Furthermore, for the first time, Professor Grau organized these neuroboxes so that they tell a coherent and progressively unfolding story across the 12 chapters. For a bird's-eye view, a list of the neuroboxes is presented in a separate section of the table of contents.

In addition to advances in the neurosciences, new research on many aspects of basic learning phenomena dictated numerous changes from the sixth to the seventh edition. The changes are too numerous to list. Among other things, they include new findings related to habit formation and automatic processing, epigenetic influences on behavior, pathological fear and post-traumatic stress disorder, individual differences in sign tracking and goal tracking, the relation of the Rescorla–Wagner model to error-correction mechanisms in robotics, new work on voucher-based programs for the treatment of substance abuse, new research on self-control, S–O and R–O associations in drug addiction, expanded and updated discussion of response allocation and behavioral economics, new research on stimulus equivalence, new work on ways to enhance extinction, new theory and research on avoidance, and extensive new sections on memory mechanisms and various special topics in comparative cognition (Chapters 11 and 12).

One of the major developments in the field during the past decade is that the basic behavioral principles that are described in this book are being utilized by an increasingly broad range of scientists. I first noticed this trend when I was preparing the sixth edition. The trend has continued since then, with the consequence that the new references that have been added in the seventh edition were culled from about 85 different journals. New information on basic learning processes continues to be published in traditional psychology journals (such as the *Journal of the Experimental Analysis of Behavior* and the *Journal of Experimental Psychology: Animal Behavior Processes*). However, important new findings are also being published in journals dealing with behavior therapy, brain research and neuroscience, biological psychiatry, child development, drug and alcohol dependence, language and cognition, family violence, neuropsychology, pharmacology and therapeutics, and psychosomatic medicine.

The broadening range of disciplines that are finding basic behavioral principles to be relevant has also been evident in the range of students who have been signing up for my learning classes. During the past two years, my graduate course on learning has attracted students from integrative biology, communications, information science, marketing, music, special education, and neuroscience, in addition to psychology.

Identifying relevant sources that appear in a diverse range of journals is made possible by the search engines of the new information age. Early editions of the book provided extensive citations of research on various topics in conditioning and learning. Considering how easy it is to find sources using ever-improving search engines, the citations in the seventh edition are not as extensive and are intended to introduce students to new lines of research rather than provide a complete list of the relevant research. I apologize to investigators whose names may have been omitted because of this altered citation strategy.

I would like to thank the support of numerous instructors and students around the world who continue to look to this book for authoritative coverage of basic learning mechanisms. Without their support, successive editions (and translations) of the book would not be possible. Successive editions of the book also would not have been possible without the support of the good folks at Cengage Learning, especially Jon-David Hague, the product director of psychology. I am also grateful to Wendy Langerud (in Iowa) and Gunjan Chandola (in India) for all of their help in shepherding the seventh edition through the complexities of the production process. Finally, I would like to thank Professor Kevin Holloway of Vassar College for agreeing to prepare the Instructor's Manual and Test Bank for the book.

*Michael Domjan*
*Austin, Texas*

# About the Authors

Courtesy of M. Domjan

**MICHAEL DOMJAN** is a professor of Psychology at the University of Texas at Austin, where he has taught learning to undergraduate and graduate students since 1973. He also served as department chair from 1999 to 2005 and was the founding director of the Imaging Research Center from 2005 to 2008. Professor Domjan is noted for his functional approach to classical conditioning, which he has pursued in studies of sexual conditioning and taste aversion learning. His research was selected for a MERIT Award by the National Institutes of Mental Health as well as a Golden Fleece Award by U.S. Senator William Proxmire. He served as editor of the *Journal of Experimental Psychology: Animal Behavior Processes* for six years and continues to serve on editorial boards of various journals in the United States and other countries. He is a past president of the Pavlovian Society and also served as president of the Division of Behavioral Neuroscience and Comparative Psychology of the American Psychological Association. His former Ph.D. students hold faculty positions at various colleges and universities in the United States, Colombia, and Turkey. Domjan also enjoys playing the viola and teaches a course on Music and Psychology in which he talks about the role of habituation, sensitization, and Pavlovian and instrumental conditioning in musical experience and musical performance.

## Neuroscience Contributor

Courtesy of James Grau

**JAMES GRAU** is a professor at Texas A&M University, with appointments in Psychology and the Texas A&M Institute for Neuroscience (TAMIN). He received his Ph.D. under the direction of Dr. R. A. Rescorla and moved to Texas A&M University in 1987, where he is now the Mary Tucker Currier Professor of Liberal Arts. He is a fellow of both the Association for Psychological Science and the American Psychological Association (Divisions 3, 6, and 28), where he served as president of Division 6 (Behavioral Neuroscience and Comparative Psychology). His research has examined how learning and memory influence pain processing, the neurobiological mechanisms involved, and how physiological observations inform our understanding of learning. His current research focuses on neural plasticity within the spinal cord, with the aim of detailing its functional properties, how and when spinal neurons learn, and the implications of this work for recovery after a spinal cord injury. His work has been funded by the National Institutes of Mental Health (NIMH), Neurological Disorders and Stroke (NINDS), and Child Health and Development (NICHD). Since 1983, he has taught nearly 50 courses and seminars on learning.

**CHAPTER 1**

# Background and Rationale for the Study of Learning and Behavior



## CHAPTER PREVIEW

The goal of Chapter 1 is to introduce the reader to contemporary studies of learning and behavior theory. I begin by characterizing behavioral studies of learning and describing how these are related to cognition and the conscious control of behavior. I then describe the historical antecedents of key concepts in modern learning theory. This is followed by a discussion of the origins of contemporary experimental research in studies of the evolution of intelligence, functional neurology, animal models of human behavior, and the implications of contemporary research for the development of memory-enhancing drugs and the construction of artificial intelligent systems or robots. I then provide a detailed definition of learning and discuss how learning can be examined at different levels of analysis. Methodological features of studies of learning are described in the next section. Because numerous experiments on learning have been performed with nonhuman animals, I conclude the chapter by discussing the rationale for the use of nonhuman animals in research, with some comments on the public debate about animal research.

People have always been interested in understanding behavior, be it their own or the behavior of others. This interest is more than idle curiosity. Our quality of life depends on our actions and the actions of others. Any systematic effort to understand behavior must include consideration of what we learn and how we learn it. Numerous aspects of the behavior of both human and nonhuman animals are the results of learning. We learn to read, to write, and to count. We learn to walk downstairs without falling, to open doors, to ride a bicycle, and to swim. We also learn when to relax and when to become anxious. We learn what foods we are likely to enjoy and what foods will make us sick. We also learn the numerous subtle gestures that are involved in effective social interactions. Life is filled with activities and experiences that are shaped by what we have learned.

Learning is one of the biological processes that facilitates our survival and promotes our well-being. When we think of survival, we typically think of the importance of biological functions such as respiration, digestion, and resisting disease. Physiological systems have evolved to accomplish these tasks. However, for many species finely tuned physiological processes do not take care of all of the adaptive functions that are required for successful existence. Learning plays a critical role in improving how organisms adapt to their environment. Sometimes this takes the form of learning new responses. In other cases, learning serves to improve how physiological systems operate to accomplish important biological functions such as digestion and reproduction (Domjan, 2005).

Animals, including people, have to learn to find new food sources as old ones become unavailable or when they move to a new area. They also have to find new shelter when storms destroy their old homes, as happens in a hurricane or tornado. Accomplishing these tasks obviously requires motor responses, such as walking and manipulating objects. These tasks also require the ability to predict important events in the environment, such as when and where food will be available. All these things involve learning. Animals learn to go to a new water hole when their old one dries up and learn to anticipate new sources of danger. These learned adjustments to the environment are as important as physiological processes such as respiration and digestion.

It is common to think about learning as involving the acquisition of new behavior. Indeed, we learn new responses when we learn to read, ride a bicycle, or play a musical instrument. However, learning can also consist of the decrease or loss of a previously performed response. A child, for example, may learn to not cross the street when the traffic light is red, to not grab food from someone else's plate, and to not yell and shout when someone is trying to take a nap. Learning to withhold or *inhibit* responses is just as important as learning to *make* responses, if not more so.

When considering learning, we are likely to think about forms of learning that require special training—the learning that takes place in schools and colleges, for example. Solving calculus problems or making a triple somersault when diving requires special instruction and lots of practice. However, we also learn all kinds of things without an expert teacher or coach during the course of routine interactions with our social and physical environment. Children learn how to open doors and windows, what to do when the phone rings, when to avoid a hot stove, and when to duck so as not to get hit by a flying ball. College students learn how to find their way around campus, how to avoid heartburn from cafeteria food, and how to predict when a roommate will stay out late at night, all without special instruction.

In the coming chapters, I will describe research on the basic principles of learning and behavior. We will focus on basic types of learning and behavior that are fundamental to life but, like breathing, are often ignored. These pervasive and basic forms of learning are a normal (and often essential) part of daily life, even though they rarely command our attention. I will describe the learning of simple relationships between events in the environment, the learning of simple motor movements, and the learning of emotional reactions to stimuli. These forms of learning are investigated in experiments that involve conditioning or "training" procedures of various sorts. However, these forms of learning occur in the lives of human and nonhuman animals without explicit or organized instruction or schooling.

Much of the research that I will describe is in the behaviorist tradition of psychology that emphasizes analyzing behavior in terms of its antecedent stimuli and consequences. Conscious reflection and conscious reasoning are deliberately left out of this analysis. I will describe automatic procedural learning that does not require awareness (e.g., Lieberman, Sunnucks, & Kirk, 1998; Smith et al., 2005) rather than declarative learning that is more accessible to conscious report.

It is natural for someone to be interested in aspects of his or her behavior that are accessible to conscious reflection. However, both psychologists and neuroscientists have become increasingly convinced that most of what we do occurs without conscious awareness. The capacity of conscious thought is very limited. That is why people have difficulty driving and talking on the phone at the same time. However, people can walk and talk at the same time because walking is a much more automatic activity that does not require conscious control. Because of the limited capacity of conscious thought, we do and learn many things without awareness. In a recent discussion of neuroscience, Eagleman (2011) noted that "there is a looming chasm between what your brain knows and what your mind is capable of accessing" (p. 55). Based on his research on the experience of conscious intent, Wegner (2002) came to a similar conclusion, which is captured in the title of his book *The Illusion of Conscious Will.* The studies of automatic procedural learning that we will discuss serve to inform us about important aspects of our behavior that we rarely think about otherwise.

The following chapters will describe how features of the environment gain the capacity to trigger our behavior whether we like it or not. This line of research has its origins in what has been called behavioral psychology. During the last quarter of the twentieth century, behavioral psychology was overshadowed by "the cognitive revolution." However, the cognitive revolution did not eliminate the taste aversions that children learn when they get chemotherapy, it did not reduce the cravings that drug addicts experience when they see their friends getting high, and it did not stop the proverbial Pavlovian dog from salivating when it encountered a signal for food. Cognitive science did not grow by taking over the basic learning phenomena that are the focus of this book. Rather, it grew by extending psychology into new areas of research such as attention, problem solving, and knowledge representation. As important as these new topics of cognitive psychology have become, they have not solved the problems of how good or bad habits are learned or how debilitating fears or emotions may be effectively modified. Those topics remain at the core of studies of learning and behavior.

Basic behavioral processes remain important in the lives of organisms even as we learn more about other aspects of psychology. In fact, there is a major resurgence of interest in basic behavioral mechanisms. This is fueled by the growing appreciation of the limited role of consciousness in behavior and the recognition that much of what takes us through our daily lives involves habitual responses that we spend little time thinking about (Gasbarri & Tomaz, 2013; Wood & Neal, 2007). We don't think about how we brush our teeth, dry ourselves after a shower, put on our clothes, or chew our food. All of these are learned responses. Behavioral models of conditioning and learning are also fundamental to the understanding of recalcitrant clinical problems such as pathological fears and phobias and drug addiction. As Wiers and Stacy (2006) pointed out, "The problem, often, is not that substance abusers do not understand that the disadvantages of continued use outweigh the advantages; rather, they have difficulty resisting their automatically triggered impulses to use their substance of abuse" (p. 292). This book deals with how such behavioral impulses are learned.

## Historical Antecedents

Theoretical approaches to the study of learning have their roots in the philosophy of René Descartes (Figure 1.1). Before Descartes, the prevailing view was that human behavior is entirely determined by conscious intent and free will. People's actions were not considered to be automatic or determined by mechanistic natural laws. What someone did was presumed to be the result of his or her will or deliberate intent. Descartes took exception to this view because he recognized that people do many things automatically in response to external stimuli. However, he was not prepared to abandon entirely the idea of free will and conscious control. He therefore formulated a dualistic view of human behavior known as Cartesian **dualism**.

According to Cartesian dualism, there are two classes of human behavior: involuntary and voluntary. Involuntary behavior consists of automatic reactions to external stimuli and is mediated by a special mechanism called a **reflex**. Voluntary behavior, by contrast, does not have to be triggered by external stimuli and occurs because of the person's conscious intent to act in that particular manner.

The details of Descartes's dualistic view of human behavior are diagrammed in Figure 1.2. Let us first consider the mechanisms of involuntary, or reflexive, behavior. Stimuli in the environment are detected by the person's sense organs. The sensory information is then relayed to the brain through nerves. From the brain, the impetus for action is sent through nerves to the muscles that create the involuntary response.

**FIGURE 1.1** René Descartes (1596–1650)

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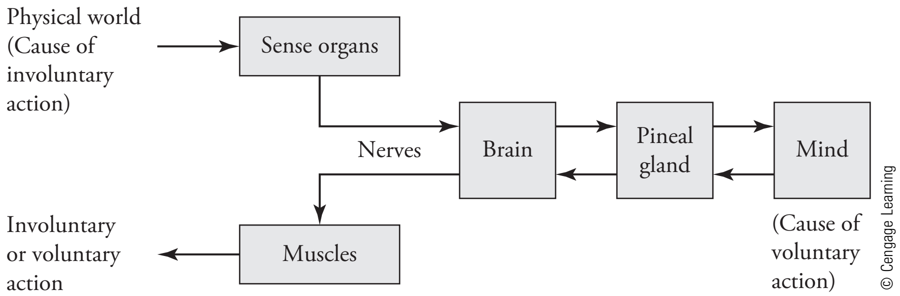


**FIGURE 1.2** Diagram of Cartesian dualism. Events in the physical world are detected by sense organs. From here the information is transmitted to the brain. The brain is connected to the mind by way of the pineal gland. Involuntary action is produced by a reflex arc that involves messages sent from the sense organs to the brain and then from the brain to the muscles. Voluntary action is initiated by the mind, with messages sent to the brain and then the muscles.

Thus, sensory input is *reflected* in the response output. Hence, Descartes called involuntary behavior *reflexive*.

Several aspects of this system are noteworthy. Stimuli in the external environment are assumed to be the cause of all involuntary behavior. These stimuli produce involuntary responses by way of a neural circuit that includes the brain. However, Descartes assumed that only one set of nerves was involved. According to Descartes, the same nerves transmitted information from the sense organs to the brain and from the brain down to the muscles. This circuit, he believed, permitted rapid reactions to external stimuli—for example, quick withdrawal of one's finger from a hot stove.

Descartes assumed that the involuntary mechanism of behavior was the only one available to animals other than humans. According to this view, all of nonhuman animal behavior occurs as reflexive behavior to external stimuli. Thus, Descartes believed that nonhuman animals lacked free will and were incapable of voluntary, conscious action. He considered free will and voluntary behavior to be uniquely human attributes. These unique human features existed because only human beings were thought to have a mind or a soul.

The mind was assumed to be a nonphysical entity. Descartes believed that the mind was connected to the physical body by way of the pineal gland, at the base of the brain. Because of this connection, the mind was aware of and could keep track of involuntary behavior. Through this mechanism, the mind could also initiate voluntary actions. Because voluntary behavior was initiated in the mind, its occurrence was not automatic and could occur independently of external stimulation.

The mind–body dualism introduced by Descartes stimulated two intellectual traditions, *mentalism* and *reflexology*. Mentalism was concerned with the contents and workings of the mind. In contrast, reflexology was concerned with the mechanisms of reflexive behavior. These two intellectual traditions form the foundations of the modern study of learning.

## Historical Developments in the Study of the Mind

Philosophers concerned with the mind pondered questions about the contents of the mind and how the mind works. These considerations formed the historical foundations of present-day cognitive psychology. Because Descartes thought the mind was connected to the brain by way of the pineal gland, he believed that some of the contents of the mind came from sense experiences. However, he also believed that the mind contained ideas that were innate and existed in all human beings independent of personal experience. For example, he believed that all humans were born with the concept of God, the concept of self, and certain fundamental axioms of geometry (such as the fact that the shortest distance between two points is a straight line). The philosophical approach that assumes we are born with innate ideas about certain things is called **nativism**.

Some philosophers after Descartes took issue with the nativist position. In particular, the British philosopher John Locke (1632–1704) proposed that all of the ideas people had were acquired directly or indirectly through experiences after birth. He believed that human beings were born without any preconceptions about the world. According to Locke, the mind started out as a clean slate (*tabula rasa*, in Latin), to be gradually filled with ideas and information as the person encountered various sense experiences. This philosophical approach to the contents of the mind is called **empiricism**. Empiricism was accepted by a group of British philosophers who lived from the seventeenth to the nineteenth century and who came to be known as the *British empiricists*.

The nativist and empiricist philosophers disagreed not only about the contents of the mind at birth but also about how the mind worked. Descartes believed that the mind did not function in a predictable and orderly manner, according to strict rules or laws that one could identify. One of the first to propose an alternative to this position was the British philosopher Thomas Hobbes (1588–1679). Hobbes accepted the distinction between voluntary and involuntary behavior stated by Descartes and also accepted the notion that voluntary behavior was controlled by the mind. However, unlike Descartes, he believed that the mind operated just as predictably and lawfully as a reflex. More specifically, he proposed that voluntary behavior was governed by the principle of **hedonism**. According to this principle, people do things in the pursuit of pleasure and the avoidance of pain. Hobbes was not concerned with whether the pursuit of pleasure and the avoidance of pain are desirable or justified. For Hobbes, hedonism was simply a fact of life. As we will see, the notion that behavior is controlled by positive and negative consequences has remained with us in one form or another to the present day.

According to the British empiricists, another important aspect of how the mind works involved the concept of **association**. Recall that the empiricists assumed that all ideas originated from sense experiences. If that is true, how do our experiences of various colors, shapes, odors, and sounds allow us to arrive at more complex ideas? Consider, for example, the concept of a car. If someone says the word *car*, you have an idea of what the thing looks like, what it is used for, and how you might feel if you sat in it. Where do all these ideas come from given just the sound of the letters *c*, *a*, and *r*? The British empiricists proposed that simple sensations were combined into more complex ideas by associations. Because you have heard the word *car* when you saw a car, considered using one to get to work, or sat in one, connections or associations became established between the word *car* and these other attributes of cars. Once the associations became established, the word *car* would activate memories of the other aspects of cars that you have experienced. The British empiricists considered such associations to be the building blocks of mental activity. Therefore, they devoted considerable effort to discovering rules of associations.

***Rules of Associations*** The British empiricists accepted two sets of rules for the establishment of associations, one primary and the other secondary. The primary rules were originally set forth by the ancient Greek philosopher Aristotle. He proposed three principles for the establishment of associations: (1) contiguity, (2) similarity, and (3) contrast. Of these, the contiguity principle has been the most prominent in studies of associations and continues to play an important role in contemporary work. It states that if two events repeatedly occur together in space or time, they will become linked or associated. For example, if you encounter the smell of tomato sauce with spaghetti often enough, your memory of spaghetti will be activated by just the smell of tomato sauce. The similarity and contrast principles state that two things will become associated if they are similar in some respect (e.g., both are red) or have some contrasting characteristics (e.g., one might be strikingly tall and the other strikingly short). Similarity as a basis for the formation of associations has been confirmed by modern studies of learning (e.g., Cusato & Domjan, 2012; Rescorla & Furrow, 1977). However, there is no contemporary evidence that contrast (making one stimulus strikingly different from another) facilitates the formation of an association between them.

Secondary laws of associations were formulated by various empiricist philosophers. Prominent among these was Thomas Brown (1778–1820), who proposed that the association between two stimuli depended on the intensity of those stimuli and how frequently or recently the stimuli occurred together. In addition, the formation of an association between two events was considered to depend on the number of other associations in which each event was already involved and the similarity of these past associations to the current one being formed.

The British empiricists discussed rules of association as a part of their philosophical discourse. They did not perform experiments to determine whether or not the proposed rules were valid. Nor did they attempt to determine the circumstances in which one rule was more important than another. Empirical investigation of the mechanisms of associations did not begin until the pioneering work of the nineteenth-century German psychologist Hermann Ebbinghaus (1850–1909).

To study how associations are formed, Ebbinghaus invented **nonsense syllables**. Nonsense syllables were three-letter combinations (e.g., "bap") devoid of any meaning that might influence how someone might react to them. Ebbinghaus used himself as the experimental subject. He studied lists of nonsense syllables and measured his ability to remember them under various experimental conditions. This general method enabled him to answer such questions as how the strength of an association improved with increased training, whether nonsense syllables that were close together in a list were associated more strongly with one another than syllables that were farther apart, and whether a syllable became more strongly associated with the next one on the list (a forward association) rather than with the preceding one (a backward association). Many of the issues that were addressed by the British empiricists and Ebbinghaus have their counterparts in modern studies of learning and memory.

## Historical Developments in the Study of Reflexes

Descartes made a very significant contribution to the understanding of behavior when he formulated the concept of the reflex. The basic idea that behavior can reflect a triggering stimulus remains an important building block of behavior theory. However, Descartes was mistaken in his beliefs about the details of reflex action. He believed that sensory messages going from sense organs to the brain and motor messages going from the brain to the muscles traveled along the same nerves. He thought that nerves were hollow tubes, and neural transmission involved the movement of gases called *animal spirits*. The animal spirits, released by the pineal gland, were assumed to flow through the neural tubes and enter the muscles, causing them to swell and create movement. Finally, Descartes considered all reflexive movements to be innate and to be fixed by the anatomy of the nervous system. Over the course of several hundred years since Descartes passed away, all of these ideas about reflexes have been proven wrong.

Charles Bell (1774–1842) in England and Francois Magendie (1783–1855) in France showed that separate nerves are involved in the transmission of sensory information from sense organs to the central nervous system and motor information from the central nervous system to muscles. If a sensory nerve is cut, the animal remains capable of muscle movements; if a motor nerve is cut, the animal remains capable of registering sensory information.

The idea that animal spirits are involved in neural transmission was also disproved. In 1669 John Swammerdam (1637–1680) showed that mechanical irritation of a nerve was sufficient to produce a muscle contraction. Thus, infusion of animal spirits from the pineal gland was not necessary. In other studies, Francis Glisson (1597–1677) tested whether muscle contractions were produced by the infusion of a gas into the muscle, as Descartes had postulated. Glisson showed that the volume of a muscle does not increase when it is contracted, demonstrating that a gas does not enter the muscle to produce motor movement.

Descartes and most philosophers after him assumed that reflexes were responsible only for simple reactions to stimuli. The energy in a stimulus was thought to be translated directly into the energy of the elicited response by the neural connections from sensory input to response output. The more intense the stimulus was, the more vigorous the resulting response would be. This simple view of reflexes is consistent with many casual observations. If you touch a stove, for example, the hotter the stove, the more quickly you withdraw your finger. However, some reflexes are much more complicated.

The physiological processes responsible for reflex behavior became better understood in the nineteenth century, and those experiments encouraged broader conceptions of reflex action. Two Russian physiologists, I. M. Sechenov (1829–1905) and Ivan Pavlov (1849–1936), were primarily responsible for these developments. Sechenov (Figure 1.3) proposed that stimuli did not elicit reflex responses directly in all cases. Rather, in some cases, a stimulus could release a response from inhibition. In instances where a stimulus released a response from inhibition, the vigor of the response would not depend on the intensity of the initiating stimulus. This simple idea opened up all sorts of new ways the concept of a reflex could be used to explain complex behavior.

If the vigor of an elicited response does not depend on the intensity of its triggering stimulus, a very faint stimulus could produce a large response. A small piece of dust in the nose, for example, can cause a vigorous sneeze. Sechenov took advantage of this type

**FIGURE 1.3**
I. M. Sechenov (1829–1905)

RIA Novosti/Alamy

of mechanism to provide a reflex model of voluntary behavior. He suggested that actions or thoughts that occurred in the absence of an obvious eliciting stimulus were in fact reflexive responses. However, in these cases, the eliciting stimuli are too faint for us to notice. Thus, according to Sechenov, voluntary behavior and thoughts are actually elicited by inconspicuous, faint stimuli.

Sechenov's ideas about voluntary behavior greatly extended the use of reflex mechanisms to explain a variety of aspects of behavior. However, his ideas were philosophical extrapolations from the actual research results he obtained. In addition, Sechenov did not address the question of how reflex mechanisms can account for the fact that the behavior of organisms is not fixed and invariant throughout an organism's lifetime but can be altered by experience. From the time of Descartes, reflex responses were considered to be innate and fixed by the connections of the nervous system. Reflexes were assumed to depend on a prewired neural circuit connecting the sense organs to the relevant muscles. According to this view, a given stimulus could be expected to elicit the same response throughout an organism's life. Although this is true in some cases, there are also many examples in which responses to stimuli change as a result of experience. Explanation of such reflexive activity had to await the work of Ivan Pavlov.

Pavlov showed experimentally that not all reflexes are innate. New reflexes to stimuli can be established through mechanisms of association. Thus, Pavlov's role in the history of the study of reflexes is comparable to the role of Ebbinghaus in the study of the mind. Both were concerned with establishing laws of associations through empirical research. However, Pavlov did this in the physiological tradition of reflexology rather than in the mentalistic tradition.

Much of modern behavior theory has been built on the reflex concept of stimulus-response or S-R unit and the concept of associations. S-R units and associations continue to play prominent roles in contemporary behavior theory. However, these basic concepts have been elaborated and challenged over the years. As I will describe in later chapters, in addition to S-R units, modern studies of learning have also demonstrated the existence of stimulus-stimulus (S-S) connections and modulatory or hierarchical associative structures (for Bayesian approaches, see Fiser, 2009; Kruschke, 2008). Quantitative descriptions of learned behavior that do not employ associations have gained favor in some quarters (e.g., Gallistel & Matzel, 2013; Leslie, 2001) and have also been emphasized by contemporary scientists working in the Skinnerian tradition of behavioral analysis (e.g., Staddon, 2001; Lattal, 2013). However, associative analyses continue to dominate behavior theory and provide the conceptual foundation for much of the research on the neural mechanisms of learning.

# The Dawn of the Modern Era

Experimental studies of basic principles of learning are often conducted with nonhuman animals and in the tradition of reflexology. Research in animal learning came to be pursued with great vigor starting a little more than a hundred years ago. Impetus for the research came from three primary sources (see Domjan, 1987). The first of these was interest in comparative cognition and the evolution of the mind. The second was interest in how the nervous system works (functional neurology), and the third was interest in developing animal models to study certain aspects of human behavior. As we will see in the ensuing chapters, comparative cognition, functional neurology, and animal models of human behavior continue to dominate contemporary research in learning.

## Comparative Cognition and the Evolution of Intelligence

Interest in comparative cognition and the evolution of the mind was sparked by the writings of Charles Darwin (Figure 1.4). Darwin took Descartes's ideas about human nature one step further. Descartes started chipping away at the age-old notion that human