CHAPTER

1

Thinking and Reasoning: A Reader's Guide

Keith J. Holyoak *and* Robert G. Morrison

"*Cogito, ergo sum*," the French philosopher René Descartes famously declared, "I think, therefore I am." Every fully functioning human adult shares a sense that the ability to think, to reason, is a part of one's fundamental identity. A person may be struck blind or deaf yet still recognize his or her core cognitive capacities as intact. Even loss of language, the gift often claimed as the *sine qua non* of *Homo sapiens*, does not take away a person's essential humanness. Perhaps thinking, not language, lies closest to both the core of our individual identity and to what is special about our species (see Penn & Povinelli, Chapter 27; Gleitman & Papafragou, Chapter 28). A person who loses language but can still make intelligent decisions, as demonstrated by actions, is viewed as mentally competent. In contrast, the kinds of brain damage that rob an individual of the capacity to think and reason are considered the harshest blows that can be struck against a sense of personhood (see Morrison & Knowlton, Chapter 6).

Cogito, ergo sum.

What Is Thinking?

We can start to answer this question by looking at the various ways the word *thinking* is used in everyday language. "I think that water is necessary for life" and "Keith and Bob think George was a fascist" both express *beliefs* (of varying degrees of apparent plausibility)—explicit claims of what someone takes to be a truth about the world. "Ann is sure to think of a solution" carries us into the realm of problem solving, the mental construction of an action plan to achieve a goal. The complaint, "Why didn't you think before you went ahead with your half-baked scheme?" emphasizes that thinking can be a kind of *foresight*, a way of "seeing" the possible future.[1] "What do you think about it?" calls for a *judgment*, an assessment of the desirability of an option. "Genocide is evil" takes judgment into the *moral* domain. And then there's "Albert is lost in thought," where thinking becomes some sort of mental meadow through which a person might meander on a rainy afternoon, oblivious to the world outside.

Rips and Conrad (1989) elicited judgments from college students about how various mentalistic terms relate to one another. Using statistical techniques, the investigators were able to summarize these relationships in two diagrams, shown in Figure 1.1. Figure 1.1A is a hierarchy of *kinds*, or categories. Roughly, people think planning is a kind of deciding, which is a kind of reasoning, which is a kind of conceptualizing, which is a kind of thinking. People also think (that verb again!) that thinking is *part of* conceptualizing, which is part of remembering, which is part of reasoning, and so on (Fig. 1.1B). The kinds ordering and the parts ordering are quite similar; most strikingly, *thinking* is the most general term in both orderings—the grand superordinate of mental activities, which permeates all the others.

Cogito, ergo sum.

It is not easy to make the move from the free flow of everyday speech to scientific definitions of mental terms, but let us nonetheless offer a preliminary definition of thinking to suggest what this book is about:

> Thinking is the systematic transformation of mental representations of knowledge to characterize actual or possible states of the world, often in service of goals.

Obviously our definition introduces a plethora of terms with meanings that beg to be unpacked, but at which we can only hint. A *mental representation* of knowledge is an internal description that

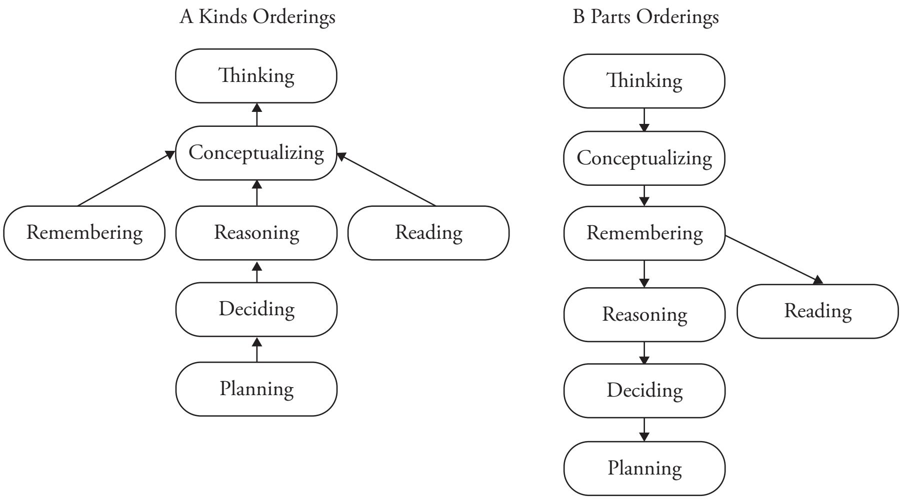

Fig. 1.1 People's conceptions of the relationships among terms for mental activities. (*A*) Ordering of "kinds." (*B*) Ordering of "parts." (Adapted from Rips & Conrad, 1989, with permission.)

can be manipulated to form other descriptions (see Markman, Chapter 4). To count as thinking, the manipulations must be *systematic* transformations that may be described computationally (see Doumas & Hummel, Chapter 5), governed by certain constraints. Whether a logical deduction (see Evans, Chapter 8) or a creative leap (see Smith & Ward, Chapter 23), what we mean by thinking is more than unconstrained associations (with the caveat that thinking may indeed be disordered; see Bachman & Cannon, Chapter 34). The internal representations created by thinking describe states of some external world (a world that may include the thinker as an object of self-reflection; see Gelman & Frazier, Chapter 26); that world might be our everyday one or perhaps some imaginary construction obeying the "laws" of magical realism. And often (not always—the daydreamer, and indeed the night dreamer, is also a thinker), thinking is directed toward achieving some desired state of affairs, some goal that motivates the thinker to do mental work (see Molden & Higgins, Chapter 20).

Our definition thus includes quite a few stipulations, but notice also what is left out. We do not claim that thinking necessarily requires a human or even a sentient being. Nonetheless, our focus in this book is on thinking by hominids with electrochemically powered brains constrained by their genes. Thinking often seems to be a conscious activity, of which the thinker is aware (*cogito, ergo sum*); but consciousness is a thorny philosophical puzzle, and some mental activities seem pretty much like thinking except for being implicit rather than explicit (see Evans, Chapter 8). Finally, we do not claim that thinking is inherently rational, or optimal, or desirable, or even smart (see Stanovich, Chapter 22). A thorough history of human thinking will include quite a few chapters on stupidity; but at its pinnacle, thinking can be sheer genius (see Simonton, Chapter 25).

The study of thinking includes several interrelated subfields, which reflect slightly different perspectives on thinking. *Reasoning,* which has a long tradition that springs from philosophy and logic, places emphasis on the process of drawing inferences (*conclusions*) from some initial information (*premises*). In standard logic, an inference is *deductive* if the truth of the premises guarantees the truth of the conclusion by virtue of the argument form. If the truth of the premises renders the truth of the conclusion more credible, but does not bestow certainty, the inference is called *inductive*.[2] *Judgment and decision making* involve assessment of the value of an option or the probability that it will yield a certain payoff (judgment), coupled with choice among alternatives (decision making). *Problem solving* involves the construction of a course of action that can achieve a goal.

Although these distinct perspectives on thinking are useful in organizing the field (and this volume), these aspects of thinking overlap in every conceivable way. To solve a problem, one is likely to reason about the consequences of possible actions and to make decisions to select among alternative actions.

A logic problem, as the name implies, is a problem to be solved (with the goal of deriving or evaluating a possible conclusion). Making a decision is often a problem that requires reasoning. And so on. These subdivisions of the field, like our preliminary definition of thinking, should be treated as guideposts, not destinations.

A Capsule History

Thinking and reasoning, long the academic province of philosophy, have over the past century emerged as core topics of empirical investigation and theoretical analysis in the modern fields known as cognitive psychology, cognitive science, and cognitive neuroscience. Before psychology was founded, the 18th-century philosophers Immanuel Kant (in Germany) and David Hume (in Scotland) laid the foundations for all subsequent work on the origins of causal knowledge, perhaps the most central problem in the study of thinking (see Cheng & Buehner, Chapter 12). And if we were to choose one phrase to set the stage for modern views of thinking, it would be an observation of the British philosopher Thomas Hobbes, who in 1651 in his treatise *Leviathan* proposed "Reasoning is but reckoning." *Reckoning* is an odd term today, but in the 17th century it meant "computation," as in arithmetic calculations.[3]

It was not until the 20th century that the psychology of thinking became a scientific endeavor. The first half of the century gave rise to many important pioneers who in very different ways laid the foundations for the emergence of the modern field of thinking and reasoning. Foremost were the Gestalt psychologists of Germany, who provided deep insights into the nature of problem solving (see Bassok & Novick, Chapter 21; van Steenburgh et al., Chapter 24). Most notable of the Gestaltists were Karl Duncker and Max Wertheimer, students of human problem solving, and Wolfgang Köhler, a keen observer of problem solving by great apes.

The pioneers of the early 20th century also include Sigmund Freud, whose complex and ever-controversial legacy includes the notions that forms of thought can be unconscious, and that "cold" cognition is tangled up with "hot" emotion (see Molden & Higgins, Chapter 20). As the founder of clinical psychology, Freud's legacy also includes the ongoing integration of research on "normal" thinking with studies of thought disorders, such as schizophrenia (see Bachman & Cannon, Chapter 34).

Other early pioneers in the early and mid-century contributed to various fields of study that are now embraced within thinking and reasoning. Cognitive development (see Gelman & Frazier, Chapter 26) continues to be influenced by the early theories developed by the Swiss psychologist Jean Piaget and the Russian psychologist Lev Vygotsky. In the United States, Charles Spearman was a leader in the systematic study of individual differences in intelligence (see Stanovich, Chapter 22). In the middle of the century, the Russian neurologist Alexander Luria made immense contributions to our understanding of how thinking depends on specific areas of the brain, anticipating the modern field of cognitive neuroscience (see Morrison & Knowlton, Chapter 6). Around the same time in the United States, Herbert Simon argued that the traditional rational model of economic theory should be replaced with a framework that accounted for a variety of human resource constraints, such as bounded attention and memory capacity and limited time (see LeBoeuf & Shafir, Chapter 16). This was one of the contributions that in 1978 earned Simon the Nobel Prize in Economics.

In 1943, the British psychologist Kenneth Craik sketched the fundamental notion that a mental representation provides a kind of model of the world that can be "run" to make predictions (much like an engineer might use a physical scale model of a bridge to anticipate the effects of stress on the actual bridge intended to span a river).[4] In the 1960s and 1970s, modern work on the psychology of reasoning began in Britain with the contributions of Peter Wason and his collaborator Philip Johnson-Laird (see Evans, Chapter 8; Johnson-Laird, Chapter 9).

The modern conception of thinking as computation became prominent in the 1970s. In their classic treatment of human problem solving, Allen Newell and Herbert Simon (1972) showed that the computational analysis of thinking (anticipated by Alan Turing, the father of computer science) could yield important empirical and theoretical results. Like a program running on a digital computer, a person thinking through a problem can be viewed as taking an input that represents initial conditions and a goal, and applying a sequence of operations to reduce the difference between the initial conditions and the goal. The work of Newell and Simon established computer simulation as a standard method for analyzing human thinking (see Doumas & Hummel, Chapter 5). It also highlighted the potential of production systems, which were subsequently developed extensively as cognitive models by John Anderson and his colleagues (see Koedinger & Roll, Chapter 40).

The 1970s saw a wide range of major developments that continue to shape the field. Eleanor Rosch, building on earlier work by Jerome Bruner (Bruner, Goodnow, & Austin, 1956), addressed the fundamental question of why people have the categories they do, and not other logically possible groupings of objects (see Rips, Smith, & Medin, Chapter 11). Rosch argued that natural categories often have fuzzy boundaries (a whale is an odd mammal), but nonetheless have clear central tendencies, or prototypes (people by and large agree that a bear makes a fine mammal). The psychology of human judgment was reshaped by the insights of Amos Tversky and Daniel Kahneman, who identified simple cognitive strategies, or heuristics, that people use to make judgments of frequency and probability. Often quick and accurate, these strategies can in some circumstances lead to nonnormative judgments. After Tversky's death in 1996, this line of work was continued by Kahneman, who was awarded the Nobel Prize in Economics in 2002. The current view of judgment that has emerged from 30 years of research is summarized by Griffin et al. (Chapter 17; also see LeBoeuf & Shafir, Chapter 16). Goldstone and Son (Chapter 10) review Tversky's influential theory of similarity judgments.

In 1982 David Marr, a young vision scientist, laid out a vision of how the science of mind should proceed. Marr distinguished three levels of analysis, which he termed the levels of *computation*, *representation and algorithm*, and *implementation*. Each level, according to Marr, addresses different questions, which he illustrated with the example of a physical device, the cash register. At Marr's most abstract level, computation (not to be confused with computation of an algorithm on a computer), the basic questions are "What is the goal that the cognitive process is meant to accomplish?" and "What is the logic of the mapping from the input to the output that distinguishes this mapping from other input-output mappings?" A cash register, viewed at this level, is used to achieve the goal of calculating how much is owed for a purchase. This task maps precisely onto the axioms of addition (e.g., the amount owed shouldn't vary with the order in which items are presented to the sales clerk, a constraint that precisely matches the commutativity property of addition). It follows that without knowing anything else about the workings of a particular cash register, we can be sure that (if it is working properly) it will be doing addition (not division).

The level of representation and algorithm, as the name implies, deals with the questions, "What is the representation of the input and output?" and "What is the algorithm for transforming the former into the latter?" Within a cash register, addition might be performed using numbers in either decimal or binary code, starting with either the leftmost or rightmost digit. Finally, the level of implementation addresses the question, "How are the representation and algorithm realized physically?" The cash register could be implemented as an electronic calculator, or a mechanical adding machine, or even a mental abacus in the mind of the clerk.

In his book, Marr stressed the importance of the computational level of analysis, arguing that it could be seriously misleading to focus prematurely on the more concrete levels of analysis for a cognitive task without understanding the goal or nature of the mental computation.[5] Sadly, Marr died of leukemia before his book was published, so we do not know how his thinking about levels of analysis might have evolved. In very different ways, Marr's conception of a computational level of analysis is reflected in several chapters in this book (see especially Chater & Oaksford, Chapter 2; Griffiths, Tenenbaum, & Kemp, Chapter 3; Cheng & Buehner, Chapter 12; and Hahn & Oaksford, Chapter 15).

In the most recent quarter century many other springs of research have fed into the river of thinking and reasoning, including relational reasoning (see Holyoak, Chapter 13), neural network models (see Doumas & Hummel, Chapter 5), cognitive neuroscience (see Morrison & Knowlton, Chapter 6), and cognitive neurogenetics (Green & Dunbar, Chapter 7). The chapters of this *Handbook* collectively paint a picture of the state of the field in the early years of the new millennium.

Overview of the *Handbook*

This volume brings together the contributions of many of the leading researchers in thinking and reasoning to create the most comprehensive overview of research on thinking and reasoning that has ever been available. Each chapter includes a bit of historical perspective on the topic and ends with some thoughts about where the field seems to be heading. The book is organized into seven sections.

Part I: General Approaches to Thinking and Reasoning

The seven chapters in Part I address foundational issues. Chapter 2 by Chater and Oaksford lays out the major normative theories (logic, probability, and rational choice) that have been used as standards against which human thinking and reasoning are often compared. In Chapter 3, Griffiths, Tenenbaum, and Kemp provide an overview of the Bayesian framework for probabilistic inference, which has been reinvigorated in recent years. Chapter 4 by Markman provides an overview of different conceptions of mental representation, and Chapter 5 by Doumas and Hummel surveys approaches to building computational models of thinking and reasoning. Then in Chapter 6, Morrison and Knowlton provide an introduction to the methods and findings of cognitive neuroscience as they bear on higher cognition, and in Chapter 7 Green and Dunbar discuss the emerging links between thinking and cognitive neurogenetics.

Part II: Inductive, Deductive, and Abductive Reasoning

Chapters 8–15 deal with core topics of reasoning. In Chapter 8, Evans reviews dual-process theories of reasoning, with emphasis on the psychology of deductive reasoning, the form of thinking with the closest ties to logic. In Chapter 9, Johnson-Laird describes the work that he and others have done using the framework of mental models to deal with various reasoning tasks, both deductive and inductive. Chapter 10 by Goldstone and Son reviews work on the core concept of similarity—how people assess the degree to which objects or events are alike. Chapter 11 by Rips, Smith, and Medin considers research on categories, and how concepts are organized in semantic memory. In Chapter 12, Cheng and Buehner discuss causal learning, a basic type of induction concerning how humans and other creatures acquire knowledge about causal relations, which are critical for predicting the consequences of actions and events. Then, in Chapter 13, Holyoak reviews the literature on reasoning by analogy and similar forms of relational reasoning. In Chapter 14, Lombrozo explores the multifaceted topic of explanation, which is closely related to abductive reasoning (often called "inference to the best explanation"). Then, in Chapter 15, Hahn and Oaksford apply the Bayesian framework to understand how people interpret informal arguments, including types of arguments that have classically been viewed as logical fallacies.

Part III: Judgment and Decision Making

In Chapters 16–20 we turn to topics related to judgment and decision making. In Chapter 16, LeBoeuf and Shafir set the stage with a general review of work on decision making. Then, in Chapter 17, Griffin, Gonzalez, Koehler and Gilovich review the fascinating literature on heuristics and biases that influence judgment. In Chapter 18, Camerer and Smith discuss behavioral game theory, an approach rooted in economics that has been applied in many other disciplines. They also touch upon recent work on neuroeconomics, the study of the neural substrate of decision making. In Chapter 19, Waldmann, Nagel, and Wiegmann review a growing literature on moral reasoning and decision making. Then, in Chapter 20, Molden and Higgins review research revealing the ways in which human motivation and emotion influence judgment.

Part IV: Problem Solving, Intelligence, and Creative Thinking

The five chapters that comprise this section deal with problem solving and the many forms of individual differences observed in human thinking. In Chapter 21, Bassok and Novick provide a general overview of the field of human problem solving. In Chapter 22, Stanovich analyzes different conceptions of rationality and discusses individual differences in both rational thought and intelligence. Problem solving has close connections to the topic of creativity, the focus of Chapter 23 by Smith and Ward. In Chapter 24, van Steenburgh, Fleck, Beeman, and Kounios review research that takes a cognitive neuroscience approach to understanding the basis for insight in problem solving. Finally, in Chapter 25 Simonton reviews what is known about the thinking processes of those who function at the extreme of individual differences commonly termed "genius."

Part V: Ontogeny, Phylogeny, Language, and Culture

Our understanding of thinking and reasoning would be gravely limited if we restricted investigation to young adult English speakers. Chapters 26–29 deal with the multifaceted ways in which aspects of thinking vary across the human life span, across species, across speakers of different languages, and its connections to larger human groups. In Chapter 26, Gelman and Frazier provide an overview of the development of thinking and reasoning over the course of childhood. In Chapter 27, Penn and Povinelli consider the fundamental question of what makes human thinking special when compared to the mental functioning of nonhuman animals. One of the most controversial topics in the field is the relationship between thinking and the language spoken by the thinker. In Chapter 28, Gleitman and Papafragou offer a fresh perspective on the hypotheses and evidence concerning the connections between language and thought. Finally, in Chapter 29, Rai discusses the ways in which human thinking can be viewed as distributed across social and cultural groups.

Part VI: Modes of Thinking

There are many modes of thinking, distinguished by broad variations in representations and processes. Chapters 30–34 consider a number of these. In Chapter 30, Opfer and Siegler discuss mathematical thinking, a special form of thinking found in rudimentary form in nonhuman animals and which undergoes complex developmental changes over the course of childhood. In Chapter 31, Hegarty and Stull review work on the role of visuospatial representations in thinking; and in Chapter 32, Goldin-Meadow and Cook discuss the ways in which spontaneous gestures reflect and guide thinking processes. In Chapter 33, McGillivray, Friedman, and Castel describe the changes in thinking and reasoning brought on by the aging process. In Chapter 34, Bachman and Cannon review research and theory concerning brain disorders, notably schizophrenia, that produce striking disruptions of normal thought processes.

Part VII: Thinking in Practice

In cultures ancient and modern, thinking is put to particular uses in special cultural practices. Chapters 35–40 focus on thinking in particular practices. In Chapter 35, Dunbar and Klahr discuss thinking and reasoning as manifested in the practice of science. In Chapter 36, Spellman and Schauer review different conceptions of legal reasoning. In Chapter 37, Patel, Arocha, and Zhang discuss reasoning in a field—medicine—in which accurate diagnosis and treatment is literally an everyday matter of life and death. Lowenstein discusses reasoning as it relates to business in Chapter 38. Thinking is also involved in many aspects of music, including composition; this topic is covered by Thompson and Ammirante in Chapter 39. Finally, Chapter 40 by Koedinger and Roll concludes the volume by considering one of the major challenges for education—finding ways to teach people to think more effectively.

Examples of Chapter Assignments for a Variety of Courses

The present volume offers a comprehensive treatment of higher cognition. As such, it serves as an excellent source for courses on thinking and reasoning, both at the graduate level and for advanced undergraduates. While instructors for semester-length graduate courses in thinking and reasoning may opt to assign the entire volume as a textbook, there are a number of other possibilities (including using chapters from this volume as introductions for various topics and then supplementing with readings from the primary literature). Here are a few examples of possible chapter groupings, tailored to a variety of possible course offerings.

Introduction to Thinking and Reasoning

1. Thinking and Reasoning: A Reader's Guide
2. Normative Systems: Logic, Probability, and Rational Choice
3. Bayesian Inference
4. Knowledge Representation
8. Dual-Process Theories of Reasoning: Facts and Fallacies
9. Inference in Mental Models
10. Similarity
11. Concepts and Categories: Memory, Meaning, and Metaphysics
12. Causal Learning and Inference
13. Analogy and Relational Reasoning
14. Explanation and Abductive Inference
15. Rational Argument
16. Decision Making
17. Judgment Heuristics
21. Problem Solving
22. On the Distinction Between Rationality and Intelligence: Implications for Understanding Individual Differences in Reasoning
23. Cognition and the Creation of Ideas

Development of Thinking

1. Thinking and Reasoning: A Reader's Guide
4. Knowledge Representation
10. Similarity
11. Concepts and Categories: Memory, Meaning, and Metaphysics
13. Analogy and Relational Reasoning
14. Explanation and Abductive Inference
26. Development of Thinking in Children
27. The Human Enigma
28. Language and Thought
30. Mathematical Cognition
31. Visuospatial Thinking
32. Gesture in Thought

33. Impact of Aging on Thinking
40. Learning to Think: Cognitive Mechanisms of Knowledge Transfer

Modeling Human Thought

1. Thinking and Reasoning: A Reader's Guide
3. Bayesian Inference
4. Knowledge Representation
5. Computational Modeling of Higher Cognition
6. Neural Substrate of Thinking
9. Inference in Mental Models
10. Similarity
11. Concepts and Categories: Memory, Meaning, and Metaphysics
12. Causal Learning and Inference
13. Analogy and Relational Reasoning
15. Rational Argument
18. Cognitive Hierarchies and Emotions in Behavioral Game Theory
40. Learning to Think: Cognitive Methods of Knowledge Transfer

Applied Thought

1. Thinking and Reasoning: A Reader's Guide
35. Scientific Thinking and Reasoning
36. Legal Reasoning
37. Thinking and Reasoning in Medicine
38. Thinking in Business
39. Musical Thought
40. Learning to Think: Cognitive Methods of Knowledge Transfer

Differences in Thought

1. Thinking and Reasoning: A Reader's Guide
19. Moral Judgment
20. Motivated Thinking
23. Cognition and the Creation of Ideas
24. Insight
25. Genius
26. Development of Thinking in Children
27. The Human Enigma
28. Language and Thought
29. Thinking in Society and Culture
32. Gesture in Thought
33. Impact of Aging on Thinking
34. The Cognitive Neuroscience of Thought Disorder in Schizophrenia

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Notes

1. Notice the linguistic connection between "thinking" and "seeing," thought and perception, which was emphasized by the Gestalt psychologists of the early 20th century.

2. The distinction between deduction and induction blurs in the study of the psychology of thinking, as we will see in Part II of this volume.

3. There are echoes of the old meaning of *reckon* in such phrases as "reckon the cost." As a further aside, the term "dead reckoning," a procedure for calculating the position of a ship or aircraft, derives from "deductive reasoning." And in an old Western movie, a hero in a tough spot might venture, "I reckon we can hold out till sun-up," illustrating how calculation has crossed over to become a metaphor for mental judgment.

4. See Johnson-Laird, Chapter 9, for a current view of thinking and reasoning that owes much to Craik's seminal ideas.

5. Indeed, Marr criticized Newell and Simon's approach to problem solving for paying insufficient attention to the computational level in this sense.

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