PART I

Cognition

CHAPTER 1

Reasoning

I am a cognitive psychologist, so it should not be surprising that the first part of the book is about cognition. The first three chapters on reasoning, problem solving, and creativity are fundamental cognitive skills that contribute to our ability to innovate as will become evident in the second part of the book on teaching these skills and the third part of the book on applying these skills. Chapters 4 and 5 are on group decision making and collaborative problem solving because innovation typically requires teamwork.

We begin with reasoning because it is required for all of the more complex skills discussed throughout the book. We also rely on reasoning throughout the day, and at times wish we had spent more time on reflection. Here is a simple example. I daily used a bottle in which I placed its black cap on a black countertop and later had trouble locating it because the two colors were identical. A month later, it occurred to me that the interior of the cap might have a different color. I can now easily locate a yellow cap by turning it over before placing it on the black surface. This is only one of the many 'I wish I would have thought of it sooner' occurrences that I (and I hope others) have experienced.

This chapter begins with the distinction between reasoning from associations and reasoning from rules – a distinction that will resurface in subsequent chapters and in the second section of this chapter on fast versus slow responses. Daniel Kahneman's (2011) best-selling book *Thinking Fast and Slow* introduced many readers to this topic. The third section on biases in reasoning describes Kahneman's classic research with Amos Tversky that was rewarded with the 2002 Nobel Prize in Economic Sciences for Daniel Kahneman following Amos Tversky's premature death in 1996. The final section of this chapter describes monitoring reasoning in which people use knowledge to improve their thinking skills.

Associations versus Rules

Steven Sloman (1996) at Brown University initially elaborated on the distinction between reasoning based on associations and reasoning based on rules. Table 1.1 lists the characteristics of the two forms of reasoning. Associative reasoning depends on similarity and associative relations such as classifying sharks as fish. Similarity relations, however, can occasionally be misleading. Whales appear similar to fish, but consulting rules avoids a misclassification. Fish lay eggs and can breathe under water. Whales cannot and therefore are not fish.

Rules depend on causal relations and the abstraction of relevant features. Examples are a list of instructions, recipes, laws, and logic. Rules help us manipulate symbols such as words by transforming an active sentence (the dog chased a ball) into a passive sentence (the ball was chased by a dog). They help us perform calculations when the symbols are numbers.

Some reasoning requires a combination of associations and rules. Children learn a multiplication table in school (6 × 6 = 36) and then rules for using these associations to solve multiplication problems (36 × 4). Rules and associations support each other in this case, but they can also conflict (Sloman, 1996). Consumer choices may be guided either by associations based on effective advertising or by a rule to save money by selecting a less costly, but equally effective, product that lacks a prominent brand name.

Sloman (1996) reports that the distinction between associations and rules is important to educational practice in two ways. Students must learn rules to provide productivity and a method for verifying conclusions but must also develop useful associations for flexible and less effortful reasoning. Useful associations guide the learner in the right direction, while rules provide a method for checking and correcting performance. A second effect on educational practice is that the distinction between associations and rules should help teachers predict which concepts learners will find difficult. Concepts should be difficult to learn when the rules are inconsistent with students' natural associations.

The distinction between automatic and strategic strategies in Table 1.1 has practical applications for selecting nudges or boosts to influence behavior. In their book *Nudge: Improving Decisions about Health, Wealth, and Happiness* (2008), Richard Thaler at the University of Chicago and Cass Sunstein at Harvard University advocated that, although people should be free to make their own choices, they should be nudged in directions that will improve their lives. Nudges try to direct people toward making good decisions as in the many government campaigns that urged people to be

Table 1.1 *Associative versus rule-based reasoning. Based on Sloman (1996)*

Characteristics	Associative system	Rule-based system
Principle of operation	Similarity	Symbol manipulation
Relations	Associations	Causal and logical
Nature of processing	Reproductive	Productive
	Automatic	Strategic
Functions	Intuition	Deliberation
	Creativity	Formal analysis
	Imagination	Verification

vaccinated against COVID-19. In 2017 Richard Thaler received the Nobel Prize in Economic Sciences for demonstrating the many beneficial effects of nudges.

An alternative to nudges is boosting. Boosting requires making an informed decision such as deciding whether to be vaccinated after studying the pros and cons of the vaccination. Ralph Hertwig in Berlin's Max Planck Institute for Human Development and Till Grune-Yanoff in Stockholm's Royal Institute of Technology (2017) classify nudging as associative processing because nudges do not require critical thinking. They classify boosting as rule-based processing because boosting creates new procedures and mental tools to help people make better decisions. The goal of boosting is to create competencies through enhancing skills, knowledge, and decision strategies. Boosts require active cooperation and investment in time, effort, and motivation (Hertwig & Grune-Yanoff, 2017).

In their sequel, *NUDGE: The Final Edition*, Thaler and Sunstein (2021) state that they are not opposed to boosting and that there is no need to select one over the other. Choices based on education are admirable, even when nudges push people in one direction. However, receiving sufficient education to make intelligent choices is unrealistic when the choices are very, very difficult. A nudge can then be helpful.

The cognitive functions of associations, listed at the bottom of Table 1.1, are particularly relevant to innovation. Robert and Michele Root-Bernstein emphasize the contribution of intuition, creativity, and imagination to innovative thinking (Root-Bernstein & Root-Bernstein, 2003). They list 13 pre-verbal, pre-logical skills for creative thinking that have been identified from hundreds of autobiographical sources, interviews, and psychological studies. The skills range from observing to synthesizing in which emotions, feelings, sensations, knowledge, and experience combine in a unified sense of comprehension. They acknowledge that education correctly emphasizes the analytical, logical, technical, objective, and descriptive aspects of each field. But they advocate in addition that the subjective, emotional, intuitive, synthetic, and sensual aspects of creativity deserve equal recognition.

One of the skills in their list – playing – occurs before formal education. Playing stimulates our minds, bodies, knowledge, and skills for the pure emotional joy of using them. It has no serious goal but is helpful for opening new areas of discovery (Root-Bernstein & Root-Bernstein, 2003). The authors refer to Alexander Calder as an example. Calder had a lifelong interest in designing toys for children before designing his innovative kinetic sculptures and free-floating mobiles. Sandra Russ (1993) documented the helpful role of play in creativity in her book *Affect and Creativity*. The book attracted early attention to this topic by discussing artistic versus scientific creativity, adjustments in the creative process, the role of computers in learning about creativity, gender differences, and enhancing creativity in home, school, and work settings.

Fast versus Slow Responses

Daniel Kahneman's (2011) book *Thinking Fast and Slow* describes two forms of reasoning that he refers to as System I and System II. System I is fast and intuitive. It aligns with the associative system in Table 1.1. System II is slow and analytical. It aligns with the rule system. Kahneman's book reveals that reasoning results in errors when people respond too quickly by relying too much on System I.

One piece of support for this claim is performance on the Cognitive Reflection Test designed by Shane Frederick when he was an assistant professor of management science at the Massachusetts Institute of Technology. The test consists of the three questions listed in Table 1.2. Try answering the questions before reading about the findings.

The purpose of the Cognitive Reflection Test is to distinguish between spontaneous and reflective responses. The incorrect spontaneous responses are 10 cents for the first question, 100 minutes for the second question, and 24 days for the third question. Reflection typically results in the correct answers. If the ball costs 5 cents, then the bat costs $1.05 and the total cost is $1.10. If 5 machines can make 5 widgets in 5 minutes, then 100 machines can make 100 widgets in 5 minutes. If lilies double in size every day, then the lake will be covered one day after it is half-filled on day 47. Check if the correct answers make sense to you after reflecting on these questions.

Table 1.2 *The cognitive reflective test*

A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost? ___ cents
If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets? _____ minutes.
In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake? _____ days.

From Frederick, S. (2005). [Copyright American Economic Association; reproduced with permission of the *Journal of Economic Perspectives*].

If you made a mistake on any of these questions, you have lots of company. Frederick (2005) found that fewer than half of the students at such elite universities as Harvard, MIT, and Princeton correctly answered all three questions. A perfect score of 3 was obtained by only 48% of the students at MIT, 26% of the students at Princeton, and 20% of the students at Harvard. These percentages were lower at less elite universities. Kahneman (2011) finds the failure to check these spontaneous responses to be remarkable because it takes only a few seconds. He reports that people apparently place too much faith in their intuitions and avoid cognitive effort to check their intuitions.

These findings should not imply that all fast responses are error-prone. Keith Stanovich (2018) at the University of Toronto proposed that answering these questions involves interaction among three stages that involve (1) activating incorrect knowledge, (2) detecting errors from spontaneous System I processing, and (3) activating correct knowledge. The three stages show how the transition from low to moderate to high knowledge influences reasoning. A key aspect of the model is whether a person has the relevant knowledge to provide a correct answer.

Let's apply the model to a hypothetical middle-school student who has been studying linear growth in class in which growth can be plotted as a straight line. She then reads the problem in Table 1.2 about when the lake will be half-filled with lily pads. The student responds, '24 days', which would be the correct answer for linear growth. This error does not conflict with the correct response because the student lacks the knowledge to answer correctly (Stage 1). Later in the year the student learns about exponential growth, which is required for a correct answer. Knowledge about both linear and exponential growth can create conflict as to which applies to a problem (Stage 2). The conflict can result in a correct response if the student overrides her initially incorrect response based on linear growth. Alternatively, the student may fail to notice the conflict so continues to misclassify the problem as linear growth. Stage 3 occurs when the student becomes expert in identifying exponential growth. In this case, her spontaneous (System 1) response regarding exponential growth is correct. An advantage of Stanovich's model is that it specifies how reasoning changes with the accumulation of knowledge.

A question raised by the model is whether successful reasoning occurs by initially generating a correct response or by overriding an incorrect response. A team of investigators in France and Canada designed a clever experiment to answer this question (Raoelison, Thompson, & De Neys, 2020). The method uses two responses to elicit both an initial intuitive response and a final, deliberative one. The instructions indicated that participants should initially respond quickly with the first answer that came to mind. The problem was then presented again with instructions to actively reflect on it before responding.

One hundred online participants took two standard reasoning tests to measure whether their reasoning ability on these conflict problems could be better predicted by their initial intuitive response or by their second deliberative response. Both intuitive and deliberative responses predicted performance on the two reasoning trials, but the initial intuitive responses made better predictions. The investigators caution that reasoning research should not overestimate the importance of deliberative correction in explaining successful reasoning. The initial intuitive answers may be correct. As indicated by Stanovich (2018), the source of correct responses depends on the level of knowledge.

Biases

The distinction between spontaneous and reflective reasoning has been one of the most important topics in the study of reasoning. Another very important topic has been the identification of various strategies people use to make numerical judgments. Amos Tversky and Daniel Kahneman referred to these strategies as heuristics – strategies that are often successful but can occasionally result in systematic biases as described in Michael Lewis's (2016) book *The Undoing Project: A Friendship That Changed Our Minds*.

One of their initial investigations studied how people judge the frequency of events. Their *availability* heuristic proposes that we estimate frequency by judging the ease with which relevant instances come to mind (Tversky & Kahneman, 1973). For example, we may estimate the

Table 1.3 *Judgments of relative frequency of causes of death. Based on Slovic, Fischoff, & Lichtenstein (1976).*

Less likely	More likely	True ratio	Percentage of correct discrimination
Asthma	Firearm accident	1.20	80
Breast cancer	Diabetes	1.25	23
Lung cancer	Stomach cancer	1.25	25
All accidents	Stroke	1.85	20
Drowning	Suicide	9.60	70
Diabetes	Heart disease	18.90	97
Tornado	Asthma	20.90	42

divorce rate in a community by recalling divorces among our acquaintances. When availability is highly correlated with actual frequency, estimates are accurate.

Some instances, however, might be difficult to retrieve from memory even though they occur frequently. The availability hypothesis predicts that frequency should be underestimated in this case. Suppose you sample a four-letter word at random from an English text. Is it more likely that the word starts with a *K* or that *K* is its third letter? The availability hypothesis proposes that people try to answer this question by judging how easy it is to think of examples in each category. Because it is easier to think of words that begin with a certain letter, people should be biased toward responding that more words start with the letter *K* than have a *K* in the third position. The median estimated ratio for each of five letters was that there were twice as many words in which that letter was the first letter rather than the third letter. The estimates were obtained despite the fact that all five letters are more frequent in the third position.

Several years later Slovic, Fischhoff, and Lichtenstein (1976) used the availability hypothesis to account for how people estimated the relative probability of 41 causes of death, including diseases, accidents, homicide, suicide, and natural hazards. A large sample of college students judged which member of a pair was the more likely cause of death. Table 1.3 shows how often they were correct for some of these pairs. The frequencies of accidents, cancer, and tornadoes – all of which receive heavy media coverage – were greatly overestimated. Asthma and diabetes, which receive less media coverage, were underestimated. For instance, the majority of students judged that tornadoes were the more likely cause of death even though death from asthma was almost 21 times greater. Examination of the events most seriously misjudged provided indirect support for the hypothesis that availability, particularly as influenced by the media, biases probability estimates.

Another heuristic that causes biases is the *representativeness* heuristic (Kahneman & Tversky, 1972). Questions about probabilities typically have the general form: (1) What is the probability that object A belongs to class B? or (2) What is the probability that process B will generate event A? People frequently answer such questions by evaluating the degree to which A is representative of B – that is, the degree to which A resembles B. When A is very similar to B, the probability that A originates from B is judged to be high. When A is not very similar to B, the probability that A originated from B is judged to be low.

One problem with basing decisions solely on representativeness is that the decisions ignore other relevant information such as *sample size*. For example, finding 600 boys in a sample of 1,000 babies was judged as likely as finding 60 boys in a sample of 100 babies, even though the latter event is much more likely. Because the similarity between the obtained proportion (0.6) and the expected proportion (0.5) is the same in both cases, people did not see any difference between them. However, statisticians tell us that it is easier to obtain a discrepancy for small samples than for large samples. The sample would, of course, be representative of the population if a researcher could sample the entire population, but populations are typically too large to make this practical.

Consider the case of McDonald's. In the mid-1990s, McDonald's did extensive group testing of the Arch Deluxe – an improved, but more expensive, version of the Big Mac. People in the test sample liked the new hamburger, but the Arch Deluxe turned out to be a failure. Those who volunteered to be included in the initial testing were likely big fans of McDonald's or hamburgers or both. But the average person goes to McDonald's for a Big Mac, not a fancy variation. The test sample did not represent the larger population of McDonald's customers, so the Arch Deluxe survived its initial, but not final, test (List, 2021).

The availability and representativeness heuristics are supplemented by other sources of bias that are discussed in Chapter 8 of *Risk: A User's Guide* by Stanley McChrystal and Anna Butico (2021). Common biases are:

- *Information sampling bias* that results in spending more time and energy on information that everyone already knows.
- *Confirmation bias* that results in searching for information that supports existing beliefs.

- *Halo effect* that results in viewing people favorably regardless of their actions.
- *Status quo bias* that results in believing that the current state of affairs is preferable.
- *Hindsight bias* that results in believing one could have predicted the outcome after observing the outcome.
- *Plan continuation bias* that results in not changing a course of action when the situation changes.
- *Ingroup bias* that results in thinking those within a group are superior to those outside the group.

An example of a person who initially benefited by these biases is Bernie Madoff, who was sentenced to a 150-year prison sentence for running a multibillion-dollar Ponzi scheme (McChrystal & Butrico, 2021). His fictional investments even fooled sophisticated investors, including corporate leaders such as those at JPMorgan. The Securities and Exchange Commission also assumed that Madoff – an experienced investor who had advised the Commission – was acting responsibly. *Risk: A User's Guide* contains many other case studies in which the failure to recognize biases increases risk. It also contains exercises for readers to apply these ideas.

Monitoring Reasoning

Let's conclude this chapter with some thoughts about monitoring reasoning. Hopefully, some of the information already presented in this chapter may help you monitor your own reasoning. You may now be more reflective before answering questions that can trick you into giving a quick but incorrect response. You may consider whether media coverage and other sources of availability bias your judgments of frequency. You may evaluate sample size as a variable that can influence the outcome of surveys and experiments.

Monitoring reasoning was a relatively unexplored topic when John Flavell introduced it in a highly cited 1979 article in the *American Psychologist* (Flavell, 1979). Previous research with preschool and elementary school children by Flavell and others had demonstrated that younger children had difficulty judging when they had learned a list of items well enough to recall them. They also believed that they had understood verbal instructions that intentionally included omissions and obscurities. These and other findings suggested that young children are quite limited in their