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The Comprehensive Assessment of Rational Thinking

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The Nobel Prize in Economics was awarded in 2002 for work on judgment and decision-making tasks that are the operational measures of rational thought in cognitive science. Because assessments of intelligence (and similar tests of cognitive ability) are taken to be the quintessence of good thinking, it might be thought that such measures would serve as proxies for the assessment of rational thought. It is important to understand why such an assumption would be misplaced. It is often not recognized that rationality and intelligence (as traditionally defined) are two different things conceptually and empirically. Distinguishing between rationality and intelligence helps explain how people can be, at the same time, intelligent *and* irrational. Thus, individual differences in the cognitive skills that underlie rational thinking must be studied in their own right because intelligence tests do not explicitly assess rational thinking. In this article, I describe how my research group has worked to develop the first prototype of a comprehensive test of rational thought (the Comprehensive Assessment of Rational Thinking).

It was truly a remarkable honor to receive the E. L. Thorndike Career Achievement Award for 2012. The list of previous winners is truly awe inspiring and humbling. One does not receive such an award without "standing on the shoulders of giants," as the saying goes. The saying usually refers to the work of previous scientists, which is certainly true in my case. But in regard to myself, I would expand the phrase to include some giant colleagues as well. I received the award for work in two disparate areas: the psychology of reasoning and the psychology of reading. In the former, which is the subject of this article, I have been blessed by the continuous collaboration of Richard West from James Madison University and Maggie Toplak from York University in Canada.

Although this article does not concern my reading work, I would be remiss if I did not acknowledge another colleague and dear friend from the days of that research: Anne Cunningham, of the University of California, Berkeley. To commemorate this award, Anne bought me a 1923 collector's copy of *Educational Psychology: Briefer Course* by the man whom we honor with this award, Edward L. Thorndike. Part 1 of this volume is titled *The Original Nature of Man*—showing that they did not shy away from bold topics and ideas in the old days! And my topic in this article most definitely follows in this "broad concept" tradition.

CONCEPTUAL CONTEXT OF THE CART

Psychology has a long and storied history (over 100 years old) of measuring the intelligence trait. Although there has been psychological work on rational thinking, this research started much later, and it was not focused on individual differences. Our research group has conducted one of the longest extant investigations of individual differences in rational thinking processes. We are near to completing (Stanovich, West, & Toplak, 2016) our work on the first prototype of a comprehensive test of rational thought (the Comprehensive Assessment of Rational Thinking [CART]), and I describe the background of our test and the nature of our progress in this article.

Note: This article is drawn from the author's E. L. Thorndike Award address presented to Division 15 of the American Psychological Association in Honolulu, HI, on August 2, 2013.

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A novice psychology student might be a bit confused at this point—thinking that somewhere along the line they have heard definitions of intelligence that included rationality. Many people—students and nonstudents alike—think that intelligence means acting rationally, more or less. Indeed, it is true that even in academic discourse many theoretical definitions of intelligence incorporate rationality by alluding to judgment and decision making in the definition (see Stanovich, 2009, for a fuller discussion). Other definitions emphasize behavioral adaptiveness and thus also fold rationality into intelligence. The problem here is that *none* of these components of rationality—adaptive responding, good judgment, and decision making—are assessed on *actual tests* of intelligence.

Publishers of IQ tests and their proponents have encouraged the view that you get everything you need in cognitive assessment from such tests. But in fact, by giving an intelligence test, one does not automatically get a measure of rational thinking. To get the latter, we need to actually construct a test of rational thinking. That is why I and my research group embarked upon creating the CART. Our premise was that because we now have conceptually grounded theories of rationality and because we have a prodigious number of tasks that measure the components of rationality (Baron, 2008; Kahneman, 2011; Stanovich, 1999, 2011), it is now possible to see what would happen if we began from the ground up to construct a rationality test around that concept only.

Synthesizing theoretical work and empirical research that began over two decades ago (Stanovich, 1993; Stanovich & West, 1997, 1998c), we now have a prototype of such a test (Stanovich et al., 2016). We have proceeded with our eyes on the empirical literature on the nature of human judgment and decision making (Kahneman, 2011; Manktelow, 2012) and theoretical discussions of rationality in cognitive science (Evans, 2014; Stanovich, 2011, 2012). For years, we have been examining how one would go about constructing the best rational thinking test if the focus was solely on that construct (as opposed to viewing its study as somehow ancillary to investigations of intelligence).

RATIONALITY IN COGNITIVE SCIENCE

We follow many cognitive science theorists in recognizing two types of rationality: instrumental and epistemic (Manktelow, 2004; Over, 2004). The simplest definition of instrumental rationality, the one that most emphasizes that it is grounded in the practical world, is this: behaving in the world so that you get exactly what you most want, given the resources (physical and mental) available to you. Somewhat more technically, we could characterize instrumental rationality as the optimization of the individual's goal fulfillment. Economists and cognitive scientists have refined the notion of optimization of goal fulfillment into the technical notion of expected utility. Epistemic rationality concerns how well beliefs map onto the actual structure of the world. The two types of rationality are related. To take actions that fulfill our goals, we need to base those actions on beliefs that are properly matched to the world.

Manktelow (2004) emphasized the practicality of both types of rationality by noting that they concern two critical things: what is true and what to do. Epistemic rationality is about what is true, and instrumental rationality is about what to do. For our beliefs to be rational they must correspond to the way the world is—they must be true. For our actions to be rational, they must be the best means toward our goals—they must be the best things to do.

More formally, economists and cognitive scientists define instrumental rationality as the maximization of expected utility (Edwards, 1954; von Neumann & Morgenstern, 1944). To be instrumentally rational, a person must choose among options based on which option has the largest expected utility. Decision situations can be broken down into three components: (a) possible actions, (b) possible states of the world, and (c) evaluations of the consequences of possible actions in each possible state of the world.

Expected utility derives from the notion of expected value. The principle of maximizing expected value says that the action that a rational person should choose is the one with the highest expected value. Expected value is calculated by taking the objective value of each outcome and multiplying it by the probability of that outcome and then summing those products over all of the possible outcomes. Symbolically, the formula is

$$\text{Expected Value} = \sum p_i v_i,$$

where p_i is the probability of each outcome and v_i is the value of each outcome. The symbol $\sum$ is the summation sign and simply means "add up all of the terms that follow." The term *utility* refers to subjective value. Thus, the calculation of expected utility involves identical mathematics, except that a subjective estimate of utility is substituted for the measure of objective value.

In practice, assessing rationality in this manner can be difficult because eliciting personal probabilities can be tricky. Also, getting measurements of the utilities of various consequences can be experimentally difficult. Fortunately, there is another useful way to measure the rationality of decisions and deviations from rationality. It has been proven through several formal analyses that if people's preferences follow certain consistent patterns (the so-called axioms of choice: independence of irrelevant alternatives, transitivity, independence, and reduction of compound lotteries, etc.), then they are behaving as if they are maximizing utility (Dawes, 1998; Edwards, 1954; Jeffrey, 1983; Luce & Raiffa, 1957; Savage, 1954; von Neumann & Morgenstern, 1944). This is the so-called axiomatic approach to whether people are maximizing utility. For example, we can test separately whether people are following the transitivity axiom: if they prefer A to B and B to C, then they should prefer A to C. Using this method makes people's degrees of rationality more easily measurable by the experimental methods of cognitive science. The deviation from the optimal choice pattern according to the axioms is an (inverse) measure of the degree of rationality.

An axiomatic approach can be applied to assessing epistemic rationality as well. Recall that the expected utility of an action involves multiplying the probability of an outcome by its utility (and summing across possible outcomes). Thus, determining the best action involves estimating the probabilities of various outcomes. For a person to be epistemically rational, their probability estimates must follow the rules of objective probabilities—their estimates must follow the so-called probability calculus. These probabilities are not conscious calculations, of course—they are one's confidence estimates about states of the world. They are one's beliefs and the confidence that one has in them. If our probabilistic judgments about the states of the world are wrong, decision making will not maximize one's utility—our actions will not result in our getting what we most want. Thus, instrumental and epistemic rationality become intertwined. If we are to determine what to do, we need to make sure that our actions are based on what is true. It is in this sense that rationality of belief—epistemic rationality—is one of the foundations for rationality of action.

THE MOST PROFOUND IRONY IN THE HISTORY OF BEHAVIORAL SCIENCE

In 2002, cognitive scientist Daniel Kahneman of Princeton University won the Nobel Prize in Economics for work done with his longtime collaborator Amos Tversky (who died in 1996). The press release for the award from the Royal Swedish Academy of Sciences drew attention to the roots of the award-winning work in "the analysis of human judgment and decision-making by cognitive psychologists." Kahneman was cited for discovering "how human judgment may take heuristic shortcuts that systematically depart from basic principles of probability."

In short, Kahneman and Tversky's work was about how humans make choices and assess probabilities, and they uncovered some very basic errors that are typical in decision making. Their work includes some of the most influential and highly cited studies in all of psychology, and it deserved to be honored with the Nobel Prize. The 1974 *Science* article by Tversky and Kahneman had, by early 2015, received more than 33,000 citations according to Google Scholar. Kahneman's (2011) recent book had received more than 6,000 citations by the same time. These numbers, along with the 2002 Nobel Prize to Kahneman, represent an unprecedented scientific influence. Yet until the CART and the work that preceded it (Bruine de Bruin, Parker, & Fischhoff, 2007; Stanovich & West, 1998c) psychologists had completely neglected to develop assessment devices for these unique cognitive skills.

One reason that this work was so influential was that it addressed deep issues concerning human rationality. Being rational means acting to achieve one's own life goals using the best means possible. To violate the thinking rules examined by Kahneman and Tversky thus has the practical consequence that we are less satisfied with our lives than we might be.

Our research group has found that there are systematic differences among individuals in the tendency to make errors of judgment and decision making (Stanovich & West, 1998c, 1999; 2000, 2008b; Toplak, West, & Stanovich, 2011, 2014). The fact that there are systematic individual differences in the judgment and decision-making situations studied by Kahneman and Tversky means that there are variations in important attributes of human cognition related to rationality—how efficient we are in achieving our goals. It is a curious fact that none of these critical attributes of human thinking are assessed on IQ tests (or their proxies such as the SAT test). This fact is curious for two related reasons. First, most laypeople are prone to think that IQ tests are tests of, to put it colloquially, good thinking. Scientists and laypeople alike would tend to agree that "good thinking" encompasses good judgment and decision making—the type of thinking that helps us achieve our goals. In fact, the type of "good thinking" that Kahneman and Tversky studied was deemed so important that research on it was awarded the Nobel Prize. Yet assessments of such good thinking are nowhere to be found on IQ tests. It is perhaps the most profound historical irony of the behavioral sciences that the Nobel Prize was awarded for studies of cognitive characteristics that are entirely missing from the most well-known mental assessment device in psychology—the intelligence test.

Critics of intelligence tests are eager to point out that the tests ignore important parts of mental life—many largely noncognitive domains such as socioemotional abilities, empathy, and interpersonal skills, for example. However, a tacit assumption in such critiques is that although intelligence tests miss certain key noncognitive areas, they do encompass most of what is important in the cognitive domain. It is just this assumption that we wish to challenge with the construction of the CART. Our test operationalizes an important cognitive domain not assessed by intelligence tests: the skills of judgment and decision making that are the foundation of rational thought and action.

THE CART AND THE HEURISTICS AND BIASES LITERATURE

In the construction of our rational thinking assessment instrument, we have drawn on the vast literature that has demonstrated that people sometimes violate the normative rules of instrumental and epistemic rationality (Baron, 2008, 2014; Evans, 2014; Kahneman, 2011; Kahneman & Tversky, 2000; Koehler & Harvey, 2004; Manktelow, 2012). We have drawn heavily on this research, especially that of the so-called heuristics and biases tradition inaugurated by Kahneman and Tversky in the early 1970s (Kahneman & Tversky, 1972, 1973; Tversky & Kahneman, 1974). The term *biases* refer to the systematic errors that people make in choosing actions and in estimating probabilities, and the term *heuristic* refers to *why* people often make these errors—because they use mental shortcuts (heuristics) to solve many problems. Table 1 lists some of the tasks, effects, and biases from this literature that we have studied in our lab and from which we selected in order to construct the CART. Because much of the operationalization of our framework of rational thinking comes from the heuristics and biases tradition, it is important to explicate the logic of such tasks.

Discussion of heuristics and biases tasks often leads to a conceptualization within a dual-process cognitive model, because most of the tasks in the heuristics and biases literature were deliberately designed to pit an automatically triggered response against a normative response generated by more controlled types of processing (Kahneman, 2011). Since Kahneman and Tversky launched the heuristics and biases approach in the 1970s, a wealth of evidence has accumulated in support of the dual-process framework (Evans & Stanovich, 2013). In many such theories, the defining feature of Type 1 processing is its autonomy—the execution of Type 1 processes is mandatory when their

TABLE 1
Sampling of the Individual Differences in Heuristics and Biases Tasks Studied in the Stanovich/West/Toplak Lab

Tasks, Effects, and Biases	*Studies of Individual Differences From the Work of Our Lab*
Baserate Neglect	Kokis et al., 2002; Stanovich & West, 1998c, 1998d, 1999, 2008b; West, Toplak, & Stanovich, 2008
Conjunction Fallacy	Stanovich & West, 1998b; Toplak, West, & Stanovich, 2011; West, Toplak, & Stanovich, 2008
Framing Effects	Stanovich & West, 1998b, 1999, 2008b; Toplak, West, & Stanovich, 2014a, 2014b
Anchoring Effect	Stanovich & West, 2008b
Sample Size Awareness	Toplak, West, & Stanovich, 2011; West, Toplak, & Stanovich, 2008
Regression to the Mean	Toplak, Liu, Macpherson, Toneatto, & Stanovich, 2007; Toplak, West, & Stanovich, 2011; West, Toplak, & Stanovich, 2008
Control Group Reasoning	Stanovich & West, 1998c; Toplak, West, & Stanovich, 2011; West, Toplak, & Stanovich, 2008
Disjunctive Reasoning	Toplak & Stanovich, 2002; West, Toplak, & Stanovich, 2008
Temporal Discounting	Toplak, West, & Stanovich, 2014a
Gambler's Fallacy	Toplak et al., 2007; Toplak, West, & Stanovich, 2011; West, Toplak, & Stanovich, 2008
Probability Matching	Stanovich & West, 2008b; Toplak et al., 2007; Toplak, West, & Stanovich, 2011; West & Stanovich, 2003
Overconfidence Effect	Stanovich & West, 1998c
Outcome Bias	Stanovich & West, 1998c, 2008b; Toplak et al., 2007; Toplak, West, & Stanovich, 2011
Ratio Bias	Kokis et al., 2002; Stanovich & West, 2008b; Toplak, West, & Stanovich, 2014a, 2014b; West, Toplak, & Stanovich, 2008
Four-Card Selection Task	Stanovich & West, 1998a, 2008b; Toplak & Stanovich, 2002; Toplak, West, & Stanovich, 2014a; West, Toplak, & Stanovich, 2008
Ignoring P(D/∼H)	Stanovich & West, 1998d, 1999; West, Toplak, & Stanovich, 2008
Sunk Cost Effect	Stanovich & West, 2008b; Toplak, West, & Stanovich, 2011
Risk/Benefit Confounding	Stanovich & West, 2008b
Covariation Detection	Stanovich & West, 1998c, 1998d; Sá, West, & Stanovich, 1999; Toplak, West, & Stanovich, 2011; West, Toplak, & Stanovich, 2008
Belief Bias in Syllogistic Reasoning	Macpherson & Stanovich, 2007; Stanovich & West, 1998c, 2008b; Toplak, West, & Stanovich, 2014a, 2014b
Omission Bias	Stanovich & West, 2008b
Informal Argument Evaluation	Stanovich & West, 1997, 2008b; Sá, West, & Stanovich, 1999
Unconfounded Hypothesis Testing	Stanovich & West, 1998c; Toplak, West, & Stanovich, 2011
Myside Bias	Sá, Kelley, Ho, & Stanovich, 2005; Stanovich & West, 2007, 2008a, 2008b; Toplak & Stanovich, 2003; Toplak, West, & Stanovich, 2014a, 2014b
Expected Value Maximization	Stanovich, Grunewald, & West, 2003; Toplak et al., 2007
Newcomb's Problem	Stanovich & West, 1999; Toplak & Stanovich, 2002
Prisoner's Dilemma	Stanovich & West, 1999; Toplak & Stanovich, 2002
Hindsight Bias	Stanovich & West, 1998c
One-side bias	Stanovich & West, 2008a
Certainty Effect	Stanovich & West, 2008b
Willingness to pay/Willingness to accept	Stanovich & West, 2008b
Bias Blind Spot	West, Meserve, & Stanovich, 2012; Toplak, West, & Stanovich, 2014a
Evaluability: Less is More Effect	Stanovich & West, 2008b
Proportion Dominance Effect	Stanovich & West, 2008b

triggering stimuli are encountered, and they are not dependent on input from high-level control systems. Autonomous processes have other correlated features—their execution tends to be rapid, they do not put a heavy load on central processing capacity, they tend to be associative—but these other correlated features are not defining (Stanovich & Toplak, 2012). The category of autonomous processes would include processes of emotional regulation, the encapsulated modules for solving specific adaptive problems that have been posited by evolutionary psychologists, processes of implicit learning, and the automatic firing of overlearned associations.

In contrast with Type 1 processing, Type 2 processing is nonautonomous. It is relatively slow and computationally expensive. Many Type 1 processes can operate in parallel, but Type 2 processing is largely serial. One of the most critical functions of Type 2 processing is to override Type 1 processing. This is sometimes necessary because autonomous processing has heuristic qualities. It is designed to get the response into the right ballpark when solving a problem or making a decision, but it is not designed for the type of fine-grained analysis called for in situations of unusual importance (financial decisions, employment decisions, legal judgments, etc.). Type 1 processing heuristics depend on benign environments. In hostile environments, they can be costly (see Hilton, 2003; Over, 2000; Stanovich, 2004).

To override Type 1 processing, Type 2 processing must display at least two related capabilities. One is the capability of interrupting Type 1 processing and suppressing its response tendencies. But suppressing the Type 1 response is not helpful unless there is a better response available to substitute for it. Where do these better responses come from? One answer is that they come from processes of hypothetical reasoning and cognitive simulation that are a unique aspect of Type 2 processing (Evans, 2010; Evans & Stanovich, 2013; Stanovich, 2004, 2011).

The really interesting issues of rationality arise when we have the possibility of different types of processing (Type 1 and Type 2) priming different responses. It is just this situation that heuristics and biases tasks put under the microscope. These tasks, interpreted within a dual-process framework (Kahneman, 2011), end up being diagnostic of the dominance of Type 1 versus Type 2 processing in determining the final response.

For a person who defaults often to Type 1 processing, environments can be either benign or hostile. A benign environment is an environment that contains useful cues that, via practice or evolutionary history, have been well represented in Type 1 subsystems. In addition, for an environment to be classified as benign, it must not contain other individuals who will adjust their behavior to exploit those relying only on Type 1 processing. In contrast, a hostile environment for heuristics is one in which there are no cues that are usable by heuristic processes, or that contains misleading cues, or that contains other agents who arrange the cues for their own advantage. We would argue (Stanovich, 2004; Stanovich & West, 2000) that the modern world is somewhat hostile to Type 1 processing in critical ways, thus making it important to assess rational thinking tendencies via the logic of heuristics and biases tasks.

It is appropriate here to emphasize another way in which intelligence tests fail to tap important aspects of rational thinking. The novice reader might have thought at this point that it seems that intelligence tests clearly measure Type 2 reasoning—that is, conscious, serial simulation of imaginary worlds in order to solve problems. This is all true, but there is a critical difference. Intelligence tests contain salient warnings that Type 2 reasoning is necessary. It is clear to someone taking an intelligence test that fast, automatic, intuitive processing will not lead to superior performance. Most tests of rational thinking do not strongly cue the subject in this manner. Instead, many heuristics and biases tasks suggest a compelling intuitive response that happens to be wrong. In heuristics and biases tasks, unlike the case for intelligence tests, the subject must detect the inadequacy of the Type 1 response and then must use Type 2 processing to both suppress the Type 1 response and to simulate a better alternative.

Most of the tasks in the heuristics and biases literature were deliberately designed to pit an intuitive but incorrect response against a normative response. This means that such tasks have both processing and knowledge requirements. From a processing standpoint, the necessity of overriding Type 1 processing must be detected. Then the intuitive response primed by Type 1 processing must be inhibited and the normative response must be retrieved or synthesized and then substituted by Type 2 processing.

In addition to these processing requirements, successful performance on heuristics and biases tasks requires the presence of several important knowledge bases. The knowledge, rules, and strategies that can be retrieved and used to replace a Type 1 intuitive response have been referred to as mindware (see Stanovich, West, & Toplak, 2011), a term coined by David Perkins in a 1995 book (Clark, 2001, used the term in a slightly different way from Perkins's original coinage). The mindware available for use during cognitive simulation is in part the product of past learning experiences. This means that there will be individual differences in the ability to simulate better alternatives to a Type 1 response based on variation in the mindware available. The mindware that allows the computation of more rational responses needs to be available and accessible during simulation activities.

Many items on the CART follow this logic. The fact that many items on the CART tap process as well as knowledge is specifically intended (as it was in the original heuristics and biases literature) and is not a flaw. It is a designed feature, not a drawback. In the domain of rational thinking, we are interested in individual differences in the *sensitivity* to probabilistic reasoning principles, for example. People can have knowledge of these principles without the propensity to use them. They can have the knowledge but not the propensity to see situations in terms of probabilities. A typical item on the CART will pit a statistical way of viewing a problem against a nonstatistical way of viewing a problem in order to see which kind of thinking dominates in the situation. So, for example, we would not design an item for which the subject chooses between a nine out of 10 chance of winning and a three out of 10 chance of winning, with no other context provided. Instead, on most of our Probabilistic Reasoning subtest items, statistical information will be given, but also a *nonstatistical* way of thinking about the problem. People who may get the pure mathematics of statistical reasoning correct might well tend not to see certain problems themselves as probabilistic. It is just this variance in sensitivity to *seeing* a problem as probabilistic that we want to assess.

THE CART TASKS AND FRAMEWORK

It is important to stress that knowledge and process are intertwined in most heuristics and biases tasks but that it is not the case that the dependence on knowledge and the dependence on process are the same for each and every task. Some heuristics and biases tasks are more process dependent than knowledge dependent. Others are more knowledge dependent than process dependent. Still others seem to stress knowledge and process both quite strongly.

Table 2 presents the overall framework for the CART, as well as some indication of the tasks used for assessment and the assessment domains. The left column of Table 2 serves to represent tasks saturated with processing requirements. The second column from the left represents tasks that are relatively saturated with knowledge from specific rational thinking domains. The first two domains of rational thinking represented in the upper left—probabilistic and statistical reasoning and scientific reasoning—have process and knowledge so intertwined that they span both columns in Table 2 to emphasize this point.

Working down the left column, Table 2 next identifies some tasks that have heavy processing requirements. In the first set, the tasks are indicators of the tendency to avoid miserly information processing. That humans are cognitive misers has been a major theme throughout the past 40 years of research in psychology and cognitive science (see Dawes, 1976; Kahneman, 2011; Simon, 1955, 1956; Taylor, 1981; Tversky & Kahneman, 1974; for the evolutionary reasons why, see Stanovich, 2004, 2009). When approaching any problem, our brains have available various computational mechanisms for dealing with the situation. These mechanisms embody a trade-off, however. The trade-off is between power and expense. Some mechanisms have great computational power—they can solve a large number of novel problems with great accuracy. However, this power comes with a cost. These mechanisms take up a great deal of attention, tend to be slow, tend to interfere with other

TABLE 2
Framework for Classifying the Types of Rational Thinking Tasks and Subtests on the Comprehensive Assessment of Rational Thinking

Tasks Saturated With Processing Requirements (Detection, Sustained Override, Hypothetical Thinking)	*Rational Thinking Tasks Saturated With Knowledge*	*Avoidance of Contaminated Mindware*	*Thinking Dispositions that Foster Thorough and Prudent Thought, Unbiased Thought, and Knowledge Acquisition*
Probabilistic and Statistical Reasoning Subtest		Superstitious Thinking Subtest	Actively Open-Minded Thinking Scale
Scientific Reasoning Subtest		Anti-Science Attitudes Subtest	Deliberative Thinking Scale
Avoidance of Miserly Information Processing Subtests: - Reflection versus Intuition - Belief Bias Syllogisms - Ratio Bias - Disjunctive Reasoning	Probabilistic Numeracy Subtest	Conspiracy Beliefs Subtest	Future Orientation Scale
Absence of Irrelevant Context Effects in Decision Making Subtests: - Framing - Anchoring - Preference Anomalies	Financial Literacy and Economic Knowledge Subtest	Dysfunctional Personal Beliefs Subtest	Differentiation of Emotions Scale
Avoidance of Myside Bias: - Argument Evaluation Subtest	Sensitivity to Expected Value Subtest		
Avoiding Overconfidence: - Knowledge Calibration Subtest	Risk Knowledge Subtest		
Rational Temporal Discounting			

thoughts and actions we are carrying out, and require great concentration that is often experienced as aversive (the Type 2 processing just discussed). Humans are cognitive misers because their basic tendency is to default to other less accurate processing mechanisms of low computational expense (the Type 1 processing just discussed).

The CART contains several subtests that assess a person's ability to avoid miserly information processing. One, the Reflection Versus Intuition subtest, was inspired by a famous problem introduced into the literature by Kahneman and Frederick (2002):

> A bat and a ball cost $1.10 in total. The bat costs $1 more than the ball. How much does the ball cost?

When they answer this problem, many people give the first response that comes to mind—10 cents—without thinking further and realizing that this cannot be correct. The bat would then have to cost $1.10, and the total cost would be $1.20 rather than the required $1.10. People often do not think deeply enough to realize their error, and cognitive ability is no guarantee against making the error. Frederick (2005) found that large numbers of highly select university students at MIT, Princeton, and Harvard were cognitive misers—they responded that the cost was 10 cents, rather than the correct answer: 5 cents.

Continuing down the left column of Table 2 are some other tasks that are best viewed as *indirect* measures of the avoidance of miserly processing. All are heavy in their processing requirements. All of these tasks and their associated effects, although involving miserly processing, are still quite complex tasks. More than miserly processing is going on when someone answers suboptimally in all of them. Our only theoretical claim is quite minimal—it is only that, whatever else is responsible for task performance, they are all likely to have miserly processing somewhat involved. In any case, they are all are important measures of rational thinking in their own right, whether or not they are due to miserly information processing. Our focus with the CART is not on resolving the theoretical disputes surrounding every one of these effects. For example, the measurement of overconfidence would be part of our rational thinking assessment battery regardless of what the explanation for the effect turns out to be. With that caveat in mind, the left-hand column of Table 2 shows several other important additional categories of our assessment battery: the absence of irrelevant context effects in decision making, the avoidance of myside bias, the avoidance of overconfidence in knowledge calibration, and rational temporal discounting of future rewards.

In the second column from the left in Table 2 are four components of the CART that represent components that are particularly heavily dependent on knowledge bases. This is not to say that these components are completely independent of the degree of miserly processing, just that variation on them is considerably less dependent on processing considerations and much more dependent on the presence of certain specific types of declarative knowledge than other tasks. These subtests of the CART tap the following: probabilistic numeracy, financial literacy and economic knowledge, sensitivity to expected value, and risk knowledge. The Probabilistic Numeracy subtest contains items such as: Imagine that an unvaccinated person has a 10% chance of getting the flu and that the flu vaccine is 80% effective in preventing the flu. What are the chances that a person who has had the vaccine will still get the flu? ______ [answer = 2%]. The Sensitivity to Expected Value subtest contains items such as: Which gamble would you prefer? (a) Gamble A has a 30% chance of winning $2,000 and a 70% chance of winning $50; (*b) Gamble B has a 30% chance of winning $400 and a 70% chance of winning $1,100. The correct choice is (b) because its expected value of $890 is higher than that of the expected value of the alternative gamble ($635).

The third column in Table 2 reflects the fact that irrational thinking is potentially caused by two different types of mindware problems. Missing mindware, or mindware gaps, reflect the most common type—where a person does not have access to adequately compiled declarative knowledge from which to synthesize a normative response to use in the override of Type 1 processing. However, I have discussed in previous publications (Stanovich, 2004, 2009, 2011) how not all mindware is helpful or useful in fostering rationality. Indeed, the presence of certain kinds of mindware is often precisely the problem. I coined the category label *contaminated mindware* for the presence of declarative knowledge bases that foster irrational rather than rational thinking.

There are probably dozens of different kinds of contaminated mindware if one looks very specifically at narrow domains of knowledge. It would obviously be impossible for a test of rational thinking to encompass all of these. Instead, we have focused on just a few of the broader categories of contaminated mindware that might have more general implications and might have some domain generality in their effects. Of course, rational thinking as indicated by CART performance is defined as the *avoidance* or *rejection* of these domains of contaminated mindware. The third column from the left in Table 2 lists the four categories of contaminated mindware that are assessed on the CART: superstitious thinking, antiscientific attitudes, conspiracy beliefs, and dysfunctional personal beliefs.

Finally, the far right column of Table 2 shows a set of supplementary measures that are included in the CART but are not part of the overall rational thinking score on the test itself. Column 4 lists some thinking dispositions that we measure by self-report questionnaires. There are many different thinking dispositions studied in psychology. However, we have chosen those specifically relevant to rational thinking. For example, we have focused on thinking dispositions that foster prudent thought and those that foster unbiased thought and unbiased knowledge acquisition. The four thinking dispositions that we assess are actively open-minded thinking, deliberative thinking, future orientation, and the differentiation of emotions. These self-report measures are different from the other performance measures on the CART, which is why they are not part of the overall score on the test but instead provide supplementary information. They are not part of the total score on the test because, among other things, the maximum score on a thinking disposition measure is not to be equated with the maximal rationality. Optimal functioning on these measures is traced instead by an inverted U-shaped function. Maximizing these dispositions is not the criterion of rational thought itself. Thinking dispositions such as these are a means to rationality, not ends in themselves. For this reason, thinking dispositions subscales are segregated in the CART and not treated as direct measures of rational thinking themselves.

Table 3 lists the subtests of the CART and the number of points allocated to that subtest, as well as the number of items that the respondent must answer to complete the subtest. The maximum score on the CART is 148, and the entire test is completed in less than 3 hr by most participants. In our book, we describe a short-form version that most people complete in less than 100 min.

TABLE 3
Comprehensive Assessment of Rational Thinking (CART) Points Allocated to Each Subtest and the Number of Items on That Subtest

CART Subtest	*CART Points*	*No. of Items*
Probabilistic and Statistical Reasoning	18	18
Scientific Reasoning	20	42
Reflection versus Intuition Subtest	10	11
Belief Bias in Syllogistic Reasoning	8	16
Ratio Bias	5	15
Disjunctive Reasoning	5	6
Framing	6	11
Anchoring	3	8
Preference Anomalies	3	9
Argument Evaluation Test	5	23
Knowledge Calibration	6	51
Rational Temporal Discounting	7	66
Probabilistic Numeracy	9	9
Financial Literacy and Economic Knowledge	10	30
Sensitivity to Expected Value	5	20
Risk Knowledge	3	14
Rejection of Superstitious Thinking	5	12
Rejection of Anti-Science Attitudes	5	13
Rejection of Conspiracy Beliefs	10	29
Avoidance of Dysfunctional Personal Beliefs	5	9
Total CART Points	148	

RATIONAL THINKING SUBSUMES CRITICAL THINKING

If one's goal is to aid people in their thinking, then it is essential that one have some way of *evaluating* thinking. For example, in the current educational literature, teachers are constantly exhorted to "teach children how to think," or to foster "critical thinking." However, the problem here is that "thinking" is not a domain of knowledge. As Baron (1993) noted,

> We teach Latin or calculus because students do not already know how to speak Latin or find integrals. But, by any reasonable description of thinking, students already know how to think, and the problem is that they do not do it as effectively as they might. (p. 199)

Thus, the admonition to educators to foster critical thinking contains implicit evaluative assumptions. The children *already* think. Educators are charged with getting them to think *better*. This of course implies a normative model of what we mean by better thinking (Baron, 1993, 2008).

A somewhat analogous issue arises when thinking dispositions are discussed in the educational literature of critical thinking. Why do we want people to think in an actively open-minded fashion? Why do we want people to be reflective? It can be argued that the superordinate goal we are actually trying to foster is that of rationality (Stanovich, 2004, 2009). That is, much of what educators are ultimately concerned about is rational thought in both the epistemic sense and the instrumental sense. We value certain thinking dispositions because we think that they will at least aid in bringing belief in line with the world (epistemic rationality) and in achieving our goals (instrumental rationality).

In short, a large part of the rationale for educational interventions to change thinking dispositions derives from a tacit assumption that actively open-minded critical-thinking dispositions make the individual a more rational person—or as Sternberg (2001, 2003) argued, a wiser, less foolish person. Thus, the normative justification for fostering critical thought is that it is the foundation of rational thought. Our view is consistent with that of many other theorists who have moved toward conceptualizing critical thinking as a subspecies of rational thinking, or at least as closely related to rational thinking (Kuhn, 2005; Moshman, 2005; Siegel, 1997).

Grounding critical thinking within the concept of rationality in this manner has many conceptual advantages. First, the concept of rationality is deeply intertwined with the data and theory of modern cognitive science (see Over, 2004; Samuels & Stich, 2004; Shafir & LeBoeuf, 2002; Stanovich, 2004, 2009) in a way that the concept of critical thinking is not. In addition, as I argued earlier in this article, theory in cognitive science differentiates rationality from intelligence and explains why rationality and intelligence often dissociate. This finding, and its explanation, confirms a long-standing belief in education that intelligence does not guarantee critical thinking.

COMPLICATIONS AND CONTEXT OF RATIONAL THINKING ASSESSMENT

For many years, I had argued (see Stanovich, 2009) that professional inertia and psychologists' investment in IQ testing have prevented us from realizing that our science had developed enough to allow us to develop a parallel RQ test. With the development of the CART, my research group has turned this prediction into reality. Although our initial effort should be viewed more as a prototype, it accomplishes the task of showing that there is nothing conceptually or theoretically preventing us from developing such a test. We know the types of thinking processes that would be assessed by such an instrument, and we have in hand prototypes of the kinds of tasks that would be used in the domains of both instrumental rationality and epistemic rationality—both of which are represented on the CART. The existence of the CART demonstrates that there is no practical limitation to constructing a rational thinking test.

Unlike many such lists of thinking skills in textbooks, the conceptual components of the CART are each grounded in a task or paradigm in the literature of cognitive science. In fact, many (e.g., context effects in decision making; probabilistic reasoning) have generated enormous empirical literatures. For example, there are many paradigms that have been used to measure the avoidance of miserly information processing (left column of Table 2, third row). The study of belief bias—that people have difficulty processing data pointing toward conclusions that conflict with what they think they know about the world—has yielded several such paradigms (e.g., Evans, Barston, & Pollard, 1983; Evans & Curtis-Holmes, 2005; Markovits & Nantel, 1989).

Another part of the CART that is richly populated by work in cognitive science is a set of tasks that collectively define the mental tendency to not be affected by irrelevant context in decision making (left column of Table 2, fourth row). All three paradigms that assess the latter tendency have each generated enormous literatures. Resistance to framing has been measured with countless tasks (e.g., Levin, Gaeth, Schreiber, & Lauriola, 2002; Maule & Villejoubert, 2007), as has the resistance to irrelevant anchoring in decisions (e.g., Epley & Gilovich, 2004, 2006; Jacowitz & Kahneman, 1995). Lichtenstein and Slovic (2006) summarized several decades worth of work on preference anomalies that followed their seminal research in the 1970s (Lichtenstein & Slovic, 1971, 1973).

The existence of the CART is my attempt to follow through on a claim made years ago (Stanovich, 2009)—that there is no *conceptual* barrier to creating a prototype of a test of rational thinking. Of course this does not mean that there is not substantial work to be done in turning the prototype into an easily usable test. We have given a book-length treatment (Stanovich et al., 2016) of the 20 years of work on individual differences in rational thinking that went into the development of our prototype. We have explored the psychometric structure of our instrument in several studies. It is important, though, to understand what various psychometric structures would—and, most important, would not—tell us. For example, if several components or measurement paradigms turn out to be highly correlated, that will make assessment more efficient and logistically easier, but it will not enhance or diminish the status of these components as aspects of rational thought. Conversely, finding that many of the components or measurement paradigms are separable in individual difference analyses in no way detracts from the importance of any component. In short, the point is that psychometric findings do not trump what cognitive scientists have found are the conceptually essential features of rational thought and action.

All of this is not to deny that it would obviously be useful to really know the structure of rational thinking skills from a psychometric point of view. Our past research has contributed substantially to clarifying that structure. We have found that certain rational thinking tasks consistently correlate with each other even after cognitive ability has been partialled out. For example, we have found that the ability to avoid belief bias in syllogistic reasoning is related to the ability to reason statistically in the face of conflicting case evidence—and that this relationship is maintained after intelligence is partialled out (Stanovich & West, 1998c; West, Toplak, & Stanovich, 2008). In addition, our group has consistently found that certain rational thinking tasks are predicted by thinking dispositions after cognitive ability has been partialled, particularly tasks involving statistical reasoning and informal argumentation (Kokis, Macpherson, Toplak, West, & Stanovich, 2002; Stanovich & West, 1997, 1998c; Toplak, West, & Stanovich, 2011, 2014a, 2014b; West, Toplak, & Stanovich, 2008).

Rationality is a multifarious concept. It is unlikely to yield as substantial a g-factor as is the case with intelligence (Deary, 2013; Hunt, 2011). Thus, assessment might be logistically difficult and reporting outcomes from a rational thinking test might be complex. However, we should not shirk from measuring something just because it is logistically difficult—particularly if the domain is important.

A reasonable amount of research has already been conducted linking rational thinking tendencies to real life decision making (Baron, Bazerman, & Shonk, 2006; Bruine de Bruin, Parker, & Fischhoff, 2007; Camerer, 2000; Fenton-O'Creevy, Nicholson, Soane, & Willman, 2003; Hilton, 2003; Milkman, Rogers, & Bazerman, 2008; Parker, Bruine de Bruin, & Fischhoff, 2015; Thaler, 2015; Thaler & Sunstein, 2008). In our book (Stanovich et al., 2016), we include a table indicating how each of the thinking skills assessed on the CART have been linked to real-life outcomes in the work of other investigators.

IMPLICATIONS OF RATIONAL THINKING ASSESSMENT

When a layperson thinks of individual differences in reasoning, that person thinks of IQ tests. It is quite natural that this is the primary association, because IQ tests are among the most publicized products of psychological research. This association is not entirely inaccurate either, because intelligence is correlated with performance on a host of reasoning tasks (Carroll, 1993; Deary, 2000; Hunt, 2011). Nonetheless, certain very important classes of individual differences in thinking are ignored if only intelligence-related variance is the primary focus. A number of these ignored classes of individual differences are those relating to rational thought.

We tend not to notice the mental processes that are missing from IQ tests, because many theorists (e.g., Gardner, 1999) have adopted a *permissive* conceptualization of intelligence rather than a grounded conceptualization. Permissive theories include aspects of functioning that are captured by the *vernacular* term intelligence (adaptation to the environment, showing wisdom, creativity, etc.) whether or not these aspects are actually measured by existing tests of intelligence. *Grounded* theories, in contrast, confine the concept of intelligence to the set of mental abilities actually tested on extant IQ tests. Adopting permissive definitions of the concept of intelligence serves to obscure what is missing from extant IQ tests. Instead, to highlight the missing elements in IQ tests, my research group has adopted a more scientifically justified grounded notion of the intelligence concept.

Grounded theories adopt the operationalization of the term that is used in both psychometric studies of intelligence and neurophysiological studies. This definition involves a statistical abstraction from performance on established tests and cognitive ability indicators. The grounded view of intelligence then takes the operationally defined construct and validates it in studies of educational attainment, cognitive neuroscience, developmental trends, and information processing.

The operationalization of rationality is different from that of intelligence, and thus, as every introductory psychology student is taught, the concepts must be treated as different. Our comprehensive test of rational thinking will go a long way toward grounding the rationality concept—a concept that captures aspects of thought that have heretofore gone unmeasured in assessment devices.

Now that we have the CART, we could, in *theory*, begin to assess rationality as systematically as we do IQ. We could choose tomorrow to more formally assess rational thinking skills, focus more on teaching them, and redesign our environment so that irrational thinking is not so costly. Whereas just 30 years ago we knew vastly more about intelligence than we knew about rational thinking, this imbalance has been redressed in the last few decades because of some remarkable work in behavioral decision theory, cognitive science, and related areas of psychology. In the past two decades cognitive scientists have developed laboratory tasks and real-life performance indicators to measure rational thinking. People have been found to differ from each other on these indicators. These indicators are structured differently from the items used on intelligence tests. We have brought this work together by producing here the first comprehensive assessment measure for rational thinking, the CART.

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