

Toplak, M. E., West, R. F., & Stanovich, K. E. (2013). Assessing the development of rationality. In H. Markovits (Ed.), *The developmental psychology of reasoning and decision-making* (pp. 7-35). NY:

2 Assessing the development of rationality

*Maggie E. Toplak, Richard F. West
and Keith E. Stanovich*

Variation in intelligence has been one of the most studied topics in psychology for many decades (Deary, 2001; Geary, 2005; Lubinski, 2004), and the development of the cognitive abilities related to intelligence is likewise a central topic in developmental science (Anderson, 2005; Bjorklund, 2004). Because assessments of intelligence (and similar tests of cognitive ability) are taken to be the sine qua non of good thinking, it might be thought that such measures would serve as proxies for the developmental trajectories for judgment and decision-making skills. It is important to understand why such an assumption would be misplaced.

Judgment and decision making are more properly regarded as components of rational thought, and 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 adolescents can be, at the same time, intelligent *and* irrational (Reyna & Farley, 2006; Stanovich, 2006). Thus, the developmental trajectories of the cognitive skills that underlie intelligence and those that underlie rational thinking must both be studied in their own right because they are conceptually and empirically separable, as we will argue in the next section. Judgment and decision-making skills, as critical components of rational thought, have a developmental trajectory that cannot just be inferred from the development of general cognitive ability.

Distinguishing rationality and intelligence in modern cognitive science

Cognitive scientists recognize two types of rationality: instrumental and epistemic. The simplest definition of instrumental rationality is: 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. The model of rational judgment used by decision scientists is one in which a person chooses options based on which option has the largest expected utility (Baron, 2008; Dawes, 1998).

The other aspect of rationality studied by cognitive scientists is termed epistemic rationality. This aspect of rationality concerns how well beliefs map onto the actual structure of the world. Epistemic rationality is sometimes called theoretical rationality or evidential rationality (Manktelow, 2004; Over, 2004). Instrumental and epistemic rationality are related. The aspects of beliefs that enter into instrumental calculations (that is, tacit calculations) are the probabilities of states of affairs in the world.

One of the fundamental advances in the history of modern decision science was the demonstration that if people's preferences follow certain patterns (the so-called axioms of choice—things like transitivity and freedom from certain kinds of context effects), they are behaving as if they are maximizing utility. They are acting to get what they most want (Luce & Raiffa, 1957; Savage, 1954). This is what makes people's degrees of rationality measurable by the experimental methods of cognitive science. Although it is difficult to assess utility directly, it is much easier to assess whether one of the axioms of rational choice is being violated. This has been the logic of the seminal heuristics and biases research program inaugurated in the much-cited studies of Kahneman and Tversky (1973, 1979; Tversky & Kahneman, 1974; see Kahneman, 2011).

Researchers in the heuristics and biases tradition have demonstrated in a host of empirical studies that people violate many of the strictures of rationality and that the magnitude of these violations can be measured experimentally. For example, people display confirmation bias, they test hypotheses inefficiently, they display preference inconsistencies, they do not properly calibrate degrees of belief, they overproject their own opinions onto others, they combine probabilities incoherently, and they allow prior knowledge to become implicated in deductive reasoning (for summaries of the large literature, see Baron, 2008; Stanovich, 2009, 2011). These are caused by many well-known cognitive biases: base-rate neglect, framing effects, representativeness biases, anchoring biases, availability bias, outcome bias, vividness effects, and various types of attribute substitution (Kahneman & Frederick, 2002), to name just a few. Degrees of rationality can be assessed in terms of the number and severity of such cognitive biases that individuals display. The important point, however, is that none of these processes are assessed directly on intelligence tests.

Conceptually as well, intelligence (as actually measured) concerns cognitive components quite different from the judgment and decision-making components that define human rationality. Intelligence, as measured on many commonly used tests, is often separated into fluid and crystallized components, deriving from the Cattell/Horn/Carroll (CHC) theory of intelligence (Carroll, 1993; Horn & Cattell, 1967). Sometimes termed the theory of fluid and crystallized intelligence (symbolized Gf/Gc theory), this theory posits that tests of mental ability tap, in addition to a general factor (*g*), a small number of broad factors, of which two are dominant (Geary, 2005; Horn & Noll, 1997). Fluid intelligence (*Gf*) reflects reasoning abilities operating across of variety of domains—in particular, novel ones. It is measured by tasks of abstract reasoning such as figural analogies, Raven Matrices, and series completion. Crystallized intelligence (*Gc*) reflects declarative knowledge acquired from acculturated learning experiences. It is measured by vocabulary

tasks, verbal comprehension, and general knowledge measures. Ackerman (1996) discusses how the two dominant factors in the CHC theory reflect a long history of considering two aspects of intelligence: intelligence-as-process (Gf) and intelligence-as-knowledge (Gc).

In our theoretical approach to intelligence, our stance has been the standard one in cognitive science—to tie the concept to the actual empirical operationalizations in the relevant literature. In the wider literature on intelligence in education, there is a contrary tradition. That contrary tradition leads to the distinction between broad and narrow theories of intelligence (Stanovich, 2009). Broad theories include aspects of functioning that are captured by the *vernacular* term intelligence (adaptation to the environment, showing wisdom, displaying creativity, etc.) *whether or not* these aspects are actually measured by existing tests of intelligence. Narrow theories of intelligence, like that adopted in our discussion, confine the concept to the set of mental abilities actually tested on extant IQ tests. Our position is that broad theories of intelligence have been the source of much confusion both within the field and among the general public. They have led to overvaluing what IQ tests can tell us about intellectual functioning.

To think rationally means adopting appropriate goals, holding beliefs that are commensurate with available evidence, and taking the appropriate action given one's goals and beliefs. None of the currently used tests of intelligence assess any of these functions. However, it could still be the case that measures of intelligence correlate with measures of rational thinking, despite the fact that the latter are not directly assessed on tests of the former. Empirically, however, research indicates that intelligence and rational thinking skills are so modestly related that the former cannot be reliably used as a proxy for the latter (see Stanovich, 2011, for a review). The developmental trajectories of judgment and decision-making skills—the skills of rational thought—must be assessed in their own right.

Assessment of the development of rational thinking

Rationality is a multifarious concept—not a single mental quality. Cognitive scientists have developed ways to test both epistemic rationality and instrumental rationality as they were defined above. For example, psychologists have studied aspects of epistemic rationality such as the ability to avoid: overconfidence in knowledge judgments; taking into account base-rates in judgments; seeking to falsify hypotheses; avoiding the tendency to try to offer causal explanations of chance events; evaluating evidence with myside bias in check; and consideration of alternative hypotheses.

Additionally, psychologists have studied aspects of instrumental rationality such as the ability to avoid: inconsistent preferences because of framing effects; avoidance of default biases; overriding the tendency to substitute affect for difficult evaluations; weighing long-term well-being over short-term rewards; recognizing when vivid stimuli and irrelevant context affect choices.

Figure 2.1 displays a framework for the assessment of the development of rational thought. The first partition in the figure indicates that rational thought

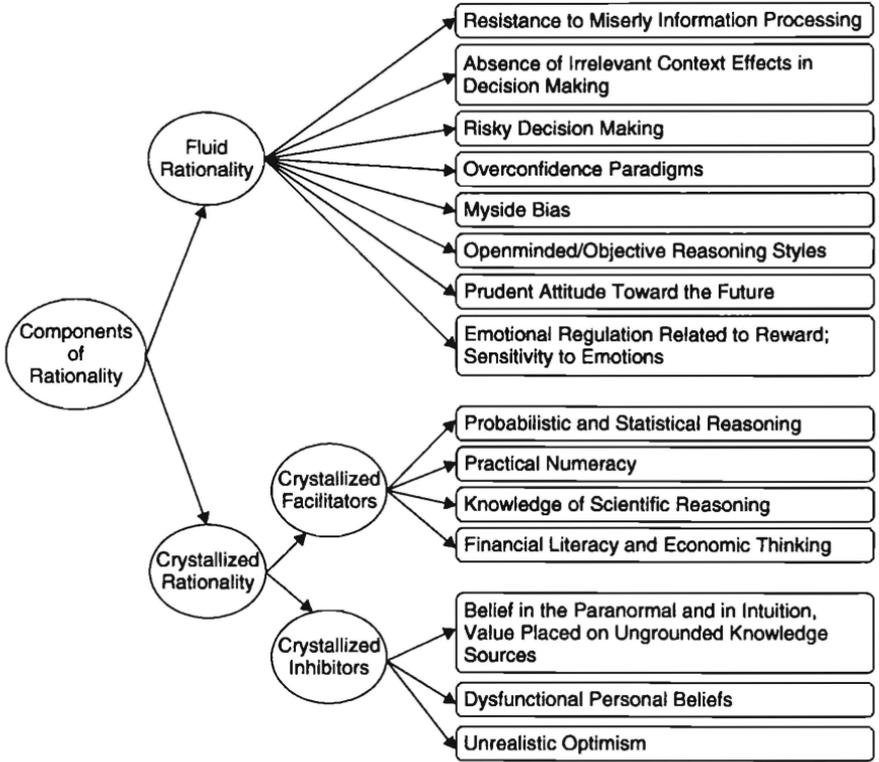


Figure 2.1 Framework for the assessment of the development of rational thought

can be partitioned into fluid and crystallized components by analogy to the Gf and Gc of the Cattell/Horn/Carroll fluid-crystallized theory of intelligence (Carroll, 1993; Cattell, 1963, 1998; Horn & Cattell, 1967). Fluid rationality encompasses the process part of rational thought—the thinking dispositions of the reflective mind (see Stanovich, 2009) that lead to rational thought and action. The top part of Figure 2.1 illustrates that unlike the case of fluid intelligence, fluid rationality is likely to be multifarious—composed of a variety of cognitive styles and dispositions. As a multifarious concept, fluid rationality cannot be assessed with a single type of item in the manner that the homogeneous Raven Progressive Matrices, for example, provides a measure of Gf.

Crystallized rationality is likewise multifarious. However, the bottom part of Figure 2.1 illustrates that the concept of crystallized rationality introduces another complication. Problems with rational thinking in the domain of mindware come in two types—mindware gaps and contaminated mindware (Stanovich, 2009). Mindware gaps occur because people lack declarative knowledge that can facilitate rational thought—they lack crystallized facilitators as indicated in Figure 2.1. A different type of mindware problem arises because not all mindware is help-

ful—either to attaining our goals (instrumental rationality) or to having accurate beliefs (epistemic rationality). In fact, some acquired mindware can be the direct cause of irrational actions that thwart our goals. This type of problem has been termed contaminated mindware (Stanovich, 2009; Stanovich, Toplak, & West, 2008). It occurs when a person has acquired one (or more) of the crystallized inhibitors listed in Figure 2.1.

Figure 2.1 presents components of rationality that are of all three types—components of fluid rationality as well as some of the most common crystallized facilitators and crystallized inhibitors. Figure 2.1 should not be mistaken for the kind of list of “good thinking styles” that appears in textbooks on critical thinking. In terms of providing a basis for a system of rational thinking assessment, it goes considerably beyond such lists in a number of ways. First, unlike the many committee-like attempts to develop feature-lists of critical thinking skills (e.g., Facione, 1990), our conceptual components are grounded in paradigms that have been extensively researched within the literature of cognitive science. This will be illustrated more concretely when we discuss Table 2.1. Second, many textbook attempts at lists of “good thinking styles” deal only with aspects of fluid rationality and give short shrift to the crystallized knowledge bases that are necessary supports for rational thought and action. In contrast, our framework for rationality assessment emphasizes that crystallized knowledge underlies much rational responding (crystallized facilitators) and that crystallized knowledge can also be the direct cause of irrational behavior (crystallized inhibitors). Even more important than these points, however, is that unlike many such lists of thinking skills in textbooks, the fluid characteristics and crystallized knowledge bases listed in Figure 2.1 are each grounded in a task or paradigm (often more than one) in the literature of cognitive science.

Table 2.1 shows some of the paradigms that ground the component concepts and that could be used as the basis for constructing test items. The left column of the table lists the major dimensions of rational thought that were illustrated in Figure 2.1. The next column lists some of the paradigms that have been used to measure that major dimension. So, for example, we can see that the major dimension of fluid rationality of resistance to miserly processing has been measured using belief bias paradigms, attribute substitution paradigms, outcome bias tasks, and hindsight bias tasks. Finally, to the right of each paradigm are some exemplars of developmental studies that have looked at the age trend of that component. In some cases where cognitive ability associations with rational thinking were indicated, these findings are also reported to examine converging (or not converging) data patterns. The paradigms we have chosen serve as pointers to the operations that might be used to measure that domain of rational thinking. Indeed, the paradigms are the actual ones we are using to develop a comprehensive device to assess rational thinking (Stanovich, 2011; Stanovich, West, & Toplak, 2011).

We present Table 2.1 as a snapshot of where the field of developmental psychology presently stands regarding empirical knowledge of the growth of components of rational thought. Because rational thinking is multifarious and complex, it will come as no surprise that there is no easy way to summarize the state of the

Table 2.1 Potential measurement paradigms for the major dimensions of rational thought and samples of developmental findings

| <i>Components of Rational Thought</i> | | |
|--|------------------------------------|---|
| <i>Fluid Rationality</i> | | |
| <i>MAJOR DIMENSIONS</i> | <i>MEASUREMENT PARADIGMS</i> | <i>DEVELOPMENTAL FINDINGS</i> |
| Resistance to Miserly Information Processing | Belief Bias Paradigm | <p>Kokis, Macpherson, Toplak, West, & Stanovich (2002): 13 year olds outperformed 11 year olds on conflict items (no-conflict items were ceiled). Higher cognitive ability (intelligence) was associated with lower belief bias.</p> <p>De Neys & Van Gelder (2009): 20 year olds outperformed both 12 year olds and 65+ year olds on a belief bias syllogistic reasoning task. No age effect was found for the no-conflict problems.</p> <p>Steegeen & De Neys (2012): 12, 14, and 17 year olds performed a belief bias syllogistic reasoning task. The older adolescents outperformed middle adolescents, who outperformed young adolescents. No age effect was found for the no-conflict problems.</p> <p>Evans & Perry (1995): 10–11 year olds displayed significantly more premise based reasoning and less belief bias than 7–8 year olds.</p> <p>Markovits & Bouffard-Bouchard (1992): 25 year olds made fewer errors on belief-biased syllogisms than 17 year olds.</p> <p>Handley, Capon, Beveridge, Dennis, & Evans (2004): 10 year olds' performance on relational conditional reasoning tasks with conflict was predicted by working memory and inhibitory control performance.</p> <p>Toplak, West, & Stanovich (in press): 13 year olds outperformed 10 year olds on a belief bias syllogistic reasoning task. Higher cognitive ability (intelligence and executive functions) was associated with lower belief bias.</p> |
| | Attribute Substitution (Vividness) | <p>Kokis et al. (2002): 13 year olds showed more reliance on noncausal baserates and less reliance on experience/case information than 11 year olds. Cognitive ability correlated positively with baserate usage.</p> <p>Jacobs & Potenza (1991): 7, 9, 11, and 20 year olds did not differ in their use of baserate information in object condition, but differed in use of baserate information in social condition.</p> <p>Davidson (1995): Older children in a sample of 8, 10, and 12 year olds were more likely to make baserate consistent responses than younger children on stereotypic and nonstereotypic problems.</p> |

| | | |
|--|---|---|
| | | Klaczynski (2001): 12 year olds showed more reliance on baserate information than 16 year olds. |
| | | Toplak et al. (in press): 11 year olds showed more reliance on baserate information than 9 year olds. Higher cognitive ability (intelligence and executive functions) was associated with less reliance on vivid individuating information. |
| | Attribute Substitution (Denominator Neglect) | Klaczynski (2001): 17 and 22 year olds showed less denominator neglect than 13 year olds. Kokis et al. (2002): 11 and 13 year olds did not differ in denominator neglect problem. Cognitive ability (intelligence) was correlated with the normative choice. Toplak et al. (in press): 11 year olds outperformed 9 year olds on a ratio bias/denominator neglect task. Higher cognitive ability (intelligence and executive functions) was associated with lower reliance on attribute substitution. |
| | Outcome Bias Paradigm | Klaczynski (2001): 16 year olds showed less Outcome Bias than 12 year olds. |
| | Hindsight Bias Paradigm | Klaczynski (2001): No significant differences between 16 year olds and 12 year olds on Hindsight Bias. |
| Absence of Irrelevant Context Effects in Decision Making | Framing Effects | Reyna & Ellis (1994): 4 year olds displayed no framing effects, 8 year olds displayed reverse framing effects, and 11 year olds displayed a mixture of framing effects. Schlottman & Tring (2005): 7 and 9 year olds preferred sure thing more in positive than negative frame in gambles with equal expected value. Toplak et al. (in press): 11 year olds were more resistant to framing than were 9 year olds in a within-subject design task. Higher cognitive ability (intelligence and executive functions) was associated with more resistance to framing. |
| | Avoidance of Irrelevant Anchoring | Smith (1999): 9, 10, and 19 year olds estimated the number of jelly beans in a container subsequent to indicating whether it held more or fewer than 50 (low anchor) or 250 (high anchor) jelly beans. An anchoring effect was found for each age group. The size of the effect did not differ between groups. |
| Risky Decision Making | Adherence to Basic Probability/Utility Tradeoffs in SEU Theory; Preferences in Line with SEU Axioms; Stable Preferences; Preference Reversals | Levin, Weller, Pederson, & Harshman (2007): Adults made more risky choices on risk-advantageous trials than 6 year olds on a risky decision-making task. Adults also made fewer risky choices on risk-disadvantageous trials than 6 and 9 year olds. Weller, Levin, & Denburg (2011): A lifespan sample of 5 to 85 year olds found that risk-taking decreased with age in the gain domain and was relatively uninfluenced by age in the loss domain. Expected value sensitivity increased from childhood to adulthood and then decreased for the elderly. |

Table 2.1 Continued

Components of Rational Thought

Fluid Rationality

| <i>MAJOR DIMENSIONS</i> | <i>MEASUREMENT PARADIGMS</i> | <i>DEVELOPMENTAL FINDINGS</i> |
|--------------------------|--|---|
| Overconfidence Paradigms | Calibration Paradigms | <p>Rakow & Rahim (2010): 21 year olds made choices more closely aligned with the expected value of observations than 9 year olds in a risky choice task that pitted risky choice against sure thing.</p> <p>Halpern-Felsher & Cauffman (2001): 11, 14, 15, 18, and 23 year olds were asked to help peers solve three hypothetical dilemmas. The 23 year olds were more likely to consider risks and benefits associated with decision and suggest seeking advice than were the adolescent and younger individuals.</p> <p>Newman (1984): 16 year olds estimated the number of dots in a series of 55 to 203 dot arrays and rated their level of confidence in each estimation. Children with higher levels of basic numerical skills made more accurate estimations and were more sensitive to variations in the difficulty of making the estimations.</p> <p>Desoete & Roeyers (2006): Grades 2, 3, and 4 children overestimated their performance in mathematics tests. The size of the overestimation was especially large for the grade 2 children.</p> <p>Schneider, Visé, Lockl, & Nelson (2000): Although 9 and 11 year olds' immediate judgments-of-learning (JOLs) in a memory task were inaccurate, their delayed JOLs improved regardless of age. JOLs were typically more accurate for aggregate JOLs than for item-by-item JOLs.</p> |
| Myside Bias | Unbiased Processing of Evidence in Argument Evaluation | <p>Klaczynski & Lavalley (2005): 17 and 22 year olds showedmyside bias in their evaluation of arguments and evidence (sample size an issue) that portrayed their vocational goals favorably or unfavorably. Age and cognitive ability did not predict additional bias beyond that associated with vocational identity and epistemic regulation.</p> <p>Klaczynski & Narasimham (1998): 11, 13, and 17 year olds showedmyside bias in their ratings of flawed experiments that reached conclusions that cast their religious views in either positive or negative light. Although scientific reasoning increased in age, age did not consistently predict the magnitude ofmyside bias.</p> |

| | | |
|---------------------------------------|--|---|
| | Informal Reasoning Paradigms and Argument Generation | Toplak & Stanovich (2003): University students generated more reasons/arguments supporting positions they endorsed than opposed. The degree of this myside bias decreased systematically with year in university. No cognitive ability effects were found. |
| Openminded/Objective Reasoning Styles | Belief Flexibility: Actively Openminded Thinking | Kokis et al. (2002): Age and cognitive ability was positively correlated with an actively open minded thinking (AOT) scale in a sample of 11 and 13 year olds. Toplak et al. (in press): Age and cognitive ability positively correlated with AOT in a sample of 9, 10, and 13 year olds. |
| | Tendency to Fully Process Information: Need for Cognition and Typical Intellectual Engagement | Baron, Granato, Spranca, & Teubal (1993): No age effect was found between actively open minded thinking scale and the search for contrary evidence in a sample of 5–12 year olds. Kokis et al. (2002): Age and need for cognition were minimally related to each other in a sample of 11 and 13 year olds. Toplak et al. (in press): No relationship between age and need for cognition in a sample of 9, 10, and 13 year olds. |
| | Separating Fact from Opinion; Recognizing the Validity and Invalidity of Informal Arguments; Recognizing Contradiction and Consistency | Kuhn (1991): The older participants in a sample of 14 to 69 year olds were less successful in generating counterarguments on 2 or 3 important issues. Kuhn, Phelps, & Walters (1985): Age in 10–12, 13–14, 15–18, and 18–31 year olds was associated with improved ability to recognize when data were sufficient for making valid causal inferences. Older participants were better able to judge when independent variables were not associated. De Neys & Everaerts (2008): Counterexample generation increased with age in 11, 15, and 17 year olds. The acceptance of invalid affirmation of the consequent decreased across these age groups. |
| Prudent Attitude Toward the Future | Temporal Discounting of Reward | Steinberg et al. (2009): 10–11 and 12–13 year olds had higher discount rates than 14–15, 16–17, 18–21, 22–25, or 26–30 year olds. In addition, delay discounting and IQ significantly negatively correlated. Green, Fry, & Myerson (1994): 12, 20, and 68 year olds showed delay discounting. Discounting was highest for the youngest and lowest for the oldest group of participants. Prencipe et al. (2006): Younger children showed steeper temporal discount rates in a sample of 9, 11, 13, and 15 year olds. Temporal discounting also significantly correlated with Digit Span (positive) and Stroop test (negative, right direction). |

Table 2.1 Continued

Components of Rational Thought

Fluid Rationality

| MAJOR DIMENSIONS | MEASUREMENT PARADIGMS | DEVELOPMENTAL FINDINGS |
|---|---|--|
| | Future Orientation; Delay of Gratification Paradigms; Time Preference | <p>Steinberg et al. (2009): 10–11, 12–13, 14–15, 16–17, 18–21, 22–25, and 26–30 year olds completed future orientation scale. Future orientation increased with age. Temporal orientation and anticipation of future consequences were associated with IQ.</p> <p>Mischel et al. (2011): Longitudinal follow-up studies of 4 year olds found that the duration that these preschoolers were able to resist the temptation of immediate rewards (e.g., a marshmallow) was significantly associated with their future cognitive abilities (e.g., SAT scores), educational achievements, and a variety of positive mental and physical health characteristics.</p> |
| Emotional Regulation Related to Reward; Sensitivity to Emotions | Iowa Gambling Task | <p>Steinberg (2010): Advantageous selection on the Iowa Gambling Task by 10–11, 12–13, 14–15, 16–17, 18–21, 22–25, and 26–30 year olds followed a curvilinear pattern, increasing between preadolescence and mid-adolescence, and then subsequently decreasing.</p> <p>Prencipe et al. (2006): Age was associated with improved performance on the Iowa Gambling, Digit Span, and Stroop tasks in a sample of 9, 11, 13, and 15 year olds.</p> <p>Lamm, Zelazo, & Lewis (2006): Advantageous selection on the Iowa Gambling Task by 7–16 year olds increased with age, and was correlated with GO RT and Go/No Go stimulus duration, but not with Digit Span.</p> <p>Crone & van der Molen (2004): Advantageous selection on an analogue of the Iowa Gambling Task by 13, 16, and 21 year olds increased with age.</p> <p>Hooper, Luciana, Conklin, & Yarger (2004): Advantageous selection on a modified Iowa Gambling Task by 10, 13, and 16 year olds increased with age.</p> |

Crystallized Rationality: Crystallized Facilitators

| MAJOR DIMENSIONS | MEASUREMENT PARADIGMS | DEVELOPMENTAL FINDINGS |
|---|---|---|
| Probabilistic and Statistical Reasoning | Consistent Probability Judgments; Conjunction Effects; Appreciating Base rate; Importance of Sample Size; Resistance to Gambler's Fallacy | Chiesi, Primi, & Morsanyi (2011): 14 year olds outperformed 12 and 13 year olds on a variety of probabilistic reasoning tasks (e.g., conjunction, gambler's fallacy, marble, sample size). Probabilistic reasoning positively associated with cognitive ability. Klaczynski (2001): 16 year olds outperformed 12 year olds on the gambler's fallacy. No significant age differences were found in conjunction bias. Falk & Wilkening (1998): Older children in a 7-age group sample of 6–14 year olds performed better than younger children on a probability-adjustment task (competitive game) Kreitler & Kreitler (1986): Older children in a 3-age group sample of 5–12 year olds performed better than younger children on Piagetian probability tasks. Fishbein & Schnarch (1997): The conjunction effect was larger for 10–11, 12–13, and 14–15 year olds than for 16–17 year olds and college students. |
| Practical Numeracy | Decision and Risk-Based Numeracy Measures | Reyna & Brainerd (2007): Results from the National Assessment of Educational Progress (NAEP) measures of mathematics indicate that approximately two-thirds of US children in the grades 4 and 8 are unable to demonstrate grade-levels of proficiency with percentages, fractions, and probabilities. Adults who lack basic proficiency in these areas have been found to comprehend medically related information less accurately and make poorer health-related decisions. |
| Knowledge of Scientific Reasoning | Control Concepts; Variable Isolation; Control Groups; Placebo and Selection Effects; Converging Evidence; Diagnostic Hypothesis Testing; Diagnostic Covariation Judgment; Understanding Falsifiability | Tschirgi (1980): 7, 9, and 11 year olds and college students were given multivariate stories and asked to determine the cause of outcomes by testing hypotheses. Development was associated with a shift in strategy choice from "change all" to "vary one thing at a time." Klahr, Fay, & Dunbar (1993): 9 and 11 year olds and college students tested hypotheses by conducting experiments. The college students were more systematic and effective in their tests, and were more likely to discover correct rules. Koslowski, Okagaki, Lorenz, & Umbach (1989): 12, 14, and 21 year olds evaluated whether target factors were causally related to effects described in story problems. Age differences were marked when covariation was present, but slight when covariation was not present. Klaczynski (2001): 16 year olds made more normative responses than 12 year olds on Wason selection and covariation detection tasks. |

| <i>Components of Rational Thought</i> | | |
|--|---|--|
| <i>Crystallized Rationality: Crystallized Facilitators</i> | | |
| <i>MAJOR DIMENSIONS</i> | <i>MEASUREMENT PARADIGMS</i> | <i>DEVELOPMENTAL FINDINGS</i> |
| | | <p>Foltz, Overton, & Ricco (1995): Although 14 year olds outperformed 10 year olds on the selection task performance, the difference did not reach a level of significance</p> <p>Richardson (1992): In contrast to 6 year olds, 10 and 14 year olds demonstrated an understanding of covariation among three variables.</p> <p>Pillow (2002): In a sample of 5, 6, 8, and 21 year olds, age was associated with increasing differentiation in certainty associated with deductive inferences, inductive inferences, informed guesses, and pure guesses.</p> <p>Masnick & Morris (2008): Compared to 9 and 12 year olds, 20 year olds detected multiple data characteristics, used multiple data characteristics in combination, and provided explicit descriptions of data interpretations compared to younger participants.</p> <p>Li, Cao, Li, & Li (2009): 9 and 11 year olds made more inductive inferences than 6 and 7 year olds on a task assessing diverse examples.</p> <p>Tullos & Woolley (2009): The ability to infer the reality status of novel entities (e.g., a new animal) from evidence (supporting, irrelevant, and no evidence) develops incrementally between ages 4 and 6, and children perform better when their evaluation is free from bias.</p> |
| Financial Literacy and Economic Thinking | <p>Financial Literacy/Illiteracy Scales</p> <p>Economic Understanding</p> <p>Avoiding Sunk Costs</p> <p>Understanding Commons Dilemmas, Zero-sum, and Nonzero-sum Games</p> | <p>Chen & Volpe (1998): College students had low levels of basic knowledge about personal finance.</p> <p>Mandell (2009): College students demonstrated higher levels of financial literacy than high school students.</p> <p>Thompson & Siegler (2000): 7 and 9 year olds, but not 5 year olds, understood the goals of seeking profits, acquiring goods inexpensively, or competing successfully with sellers.</p> <p>Klaczynski (2001): 17 and 22 year olds outperformed 13 year olds on sunk cost problem.</p> <p>Strough et al. (2008): 74 year olds adults were less likely to show sunk cost effect than 19 year olds.</p> <p>Brady, Newcomb, & Hartup (1983): 1st, 3rd, and 5th graders played a board game with many complex variations but there was a mild trend to increase cooperation with age.</p> |

Crystallized Rationality: Crystallized Inhibitors

| MAJOR DIMENSIONS | MEASUREMENT PARADIGMS | DEVELOPMENTAL FINDINGS |
|---|--|---|
| Belief in the Paranormal and in Intuition; Value Placed on Ungrounded Knowledge Sources | Paranormal, Superstitious Thinking, Luck scales, Intuition | <p>Kokis et al. (2002): Age and cognitive ability were negatively associated with superstitious thinking in a sample of 10–11 and 13 year olds.</p> <p>Toplak et al. (in press): Age and cognitive ability were negatively associated with superstitious thinking in a sample of 9, 10, and 13 year olds.</p> <p>Preece & Baxter (2000): Skepticism about superstitious and pseudoscientific beliefs was increased with age in a sample of 14–16 and 17–18 year olds.</p> <p>Bolton, Dearsley, Madronal-Luque, & Baron-Cohen (2002): Scores on the Magical Thinking Questionnaire (MTQ) were not systematically associated with age in a sample of 5–17 year olds. Magical thinking and obsessive compulsion were correlated.</p> |
| Dysfunctional Personal Beliefs | Measures of Irrational Personal Beliefs | <p>Bernard & Cronan (1999): Child and Adolescent Scale of Irrationality (CASI) was given to grades 4–11 children. Total irrationality and the four irrational subscales with trait anxiety, anger, as well as with teacher ratings of students were correlated.</p> <p>Hooper & Layne (1983): No significant differences between 5th, 6th, and 7th graders on Common Belief Inventory for students (CBIS), a measure of irrational personal beliefs.</p> |
| Unrealistic Optimism | Unrealistic Optimism Measures | Cohn, Macfarlane, Yanez, & Imai (1995): Compared with their parents, 13–18 year olds minimized the harm associated with periodic involvement in health-threatening activities. |

literature. This table is not exhaustive of developmental studies that have examined related paradigms, but rather provides pointers to paradigms from the cognitive science literature that have been examined in the developmental literature.

Empirical trends in the development of rational thinking

Predictably, some of the subcomponents of rational thought have received more attention than others. For example, the major dimension of resistance to miserly processing has been relatively heavily investigated with a variety of different paradigms. Within that dimension, 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 produced a substantial literature of developmental studies. In contrast, another major dimension of fluid rationality—the avoidance of myside bias—has received much less attention.

The complexity of the entire framework makes *general* statements about developmental trends difficult. Sometimes there is convergence within the paradigms of a major dimension and sometimes not. Often, there is convergence within a *paradigm*, but sometimes there is a lack of convergence even there. We will non-exhaustively (due to the complexity and size of Table 2.1) give some examples of each of these situations of convergence and nonconvergence.

The assessment of rational thought in developmental studies

Table 2.1 provides a summary of developmental studies that have examined rational thinking in our taxonomy.

Fluid rationality

Fluid rationality is the largest domain encompassing the processing components of rational thinking; they are the “thinking dispositions of the reflective mind that lead to rational thought and action” (Stanovich, 2011, p. 193).

Resistance to miserly information processing

Belief bias, attribute substitution, and denominator neglect each involve a default to miserly information processing (Stanovich, 2009, 2011; Stanovich et al., 2008). The experimental paradigms used to operationalize them have been well-documented in the adult literature (Denes-Raj & Epstein, 1994; Evans, Barston, & Pollard, 1983; Kahneman & Frederick, 2002) and have been used in multiple studies in the developmental literature (Stanovich et al., 2008).

Belief bias syllogistic reasoning paradigms involve a conflict between the logical structure of a syllogism and the believability of its conclusion. In these tasks, participants are given explicit instructions to assume that the premises are true and to determine whether the conclusion follows logically from the premises. For example, given the following information: All living things need

water (Premise 1), and roses need water (Premise 2), does it logically follow that roses are living things (Conclusion)? In this case, the conclusion does not logically follow from the premises, even though the conclusion is a believable statement. Studies that have examined belief bias reasoning in developmental samples have generally found that older children outperform younger children (De Neys & Van Gelder, 2009; Evans & Perry, 1995; Kokis et al., 2002; Markovits & Bouffard-Bouchard, 1992; Markovits & Thompson, 2008; Markovits et al., 1996; Moshman & Franks, 1986; Steegen & De Neys, 2012; Toplak et al., in press; but see Morsanyi & Handley, 2008). A converging pattern has also been reported with cognitive abilities. Better performance on intelligence and executive function measures has been associated with better performance on belief bias tasks in developmental samples (Handley et al., 2004; Kokis et al., 2002; Toplak et al., in press).

Vividness effects, which are indicators of attribute substitution (Fong, Krantz, & Nisbett, 1986; Stanovich et al., 2008), also reflect a default to miserly information processing (Stanovich, 2009; 2011; Stanovich et al., 2008). In these problems, participants are asked to make a choice informed by large-sample information versus salient personal testimony. Reliance on information from the large samples is normative and must override the cognitive miser's tendency to rely on the vivid and salient single-case testimony. Several studies have reported that increasing age is associated with more reliance on base rates and less reliance on salient vivid cases in older children and youth than in younger children (Kokis et al., 2002; Davidson, 1995; Klaczynski, 2001; Toplak et al., in press). Cognitive ability has also been reported to be significantly positively associated with base rate usage (Kokis et al., 2002; Toplak et al., in press). However, some studies have reported finding increased reliance on salient vivid cases in older participants when social stereotypes are involved (Davidson, 1995; De Neys & Vandermatte, 2011; Jacobs & Potenza, 1991). A plausible explanation of this finding is that it results from an increased knowledge of the stereotype that accompanies an increase in age (Stanovich et al., 2008).

Denominator neglect provides another example of the cognitive miser's failure to override a heuristic response (Denes-Raj & Epstein, 1994; Kirkpatrick & Epstein, 1992; Pacini & Epstein, 1999). Adults were presented with two bowls of jelly beans: one bowl had 9 white jelly beans and one red jelly bean, and the other bowl had 92 white jelly beans and 8 red jelly beans. The task was to randomly select a bean from whichever bowl offered the greatest chance of selecting a red bean for a one dollar prize. Although the majority picked the 10 percent bowl, a healthy minority (from 30 to 40 percent of the participants) picked the 8 percent bowl.

Using this paradigm, Kokis et al. (2002) found no significant trend for denominator neglect to decrease across groups of 10–11 year olds and 13–14 year olds. However, Klaczynski (2001) found that 17 and 22 year olds outperformed 13 year olds, and Toplak et al. (in press) found a developmental effect on a variant of this task with 9 and 11 year olds (see also Acredolo, O'Connor, Banks, & Horobin, 1989; Furlan, Agnoli, & Reyna, 2012; Stanovich et al., 2008).

Although less frequently used with developmental samples, outcome bias and hindsight bias paradigms provide additional indicators of the tendency toward myside processing.

Absence of irrelevant context effects in decision making

Framing effects represent an example from the classic heuristics and biases literature of defaulting to a cognitive miser with a focal bias (Stanovich, 2009, 2011). Framing effects reflect the passive acceptance of—and differential response to—what are in fact mere re-descriptions of the same situation. For example, participants in Tversky and Kahneman's (1981) famous disease framing problem were risk averse when framing emphasized gains ("200 [of 600] people will be saved"), but risk seeking when framing emphasized losses ("400 [of 600] people will die").

Relative to the vast adult literature (Kahneman & Tversky, 1984, 2000; Kühberger, 1998; Levin, Gaeth, Schreiber, & Lauriola, 2002; Maule & Villejoubert, 2007), the literature on framing effects with children is relatively sparse. Some investigators have creatively adapted framing paradigms for children (Levin & Hart, 2003; Reyna & Ellis, 1994; Schlottman & Tring, 2005), but the results of these experiments have not converged (Stanovich et al., 2008). Toplak et al. (in press) presented 9 and 11 year olds with positively and negatively framed versions of the same problems using a within-subject design. For example, one framing of a question for participants read: "Imagine that Jimmy played 8 games at a carnival. He won 6 of the 8 games he played. Rate how happy Jimmy was after playing the carnival games." This question was identical in the second framing except that this time Jimmy "lost 2 of the 8 games." The 11 year olds were more resistant to the framing manipulation than the 9 year olds. In addition, higher cognitive abilities (intelligence and executive function performance) were associated with more resistance to framing. These findings are consistent with the adult literature, where framing effects have been found to be associated with cognitive abilities in within-subject designs, but not in between-subject designs (Stanovich & West, 2008b). Other developmental patterns are discussed by Reyna and Ellis (1994).

Avoidance of irrelevant anchoring is another paradigm that has been used widely to assess context effects in decision making in adults, but sparingly with children.

Risky decision making

Higher levels of education and cognitive ability are associated with increased preference for gambles with risky but higher expected values over certain but lower values in adults (Benjamin & Shapiro, 2005; Donkers, Melenberg, & van Soest, 2001; Frederick, 2005). The "cups" task has been used to examine risky decision making in developmental samples (Levin, Weller, Pederson, & Harshman, 2007; Weller, Levin, & Denburg, 2011). Three variables were manipulated: gain versus

loss trials, different levels of probability for the risky choices (0.20, 0.33, 0.50), and different levels of outcomes. Each trial required a choice between a certain or risky option. For example, participants choose between a sure gain of 25 cents and a 20 percent chance of winning 50 cents. The risky option offered either a higher or lower expected value. Feedback was given following each choice, and the accumulated money earned was received at the conclusion of the experiment. Adults were more likely to select the options that offered higher expected values than children (Levin et al., 2007; Weller et al., 2011). This developmental finding has been replicated using somewhat different procedures (Rakow & Rahim, 2010, but see Schlottmann, 2000, 2001).

Overconfidence

Overconfidence is an important domain of fluid rationality. It has been assessed using knowledge calibration paradigms that compare a participant's estimation of the likelihood of an outcome with its actual statistical likelihood. For example, Fischhoff et al. (2000) asked adolescents to report how likely it was that they "will be a parent between now and when they turn 20 years of age," "will be the victim of a violent crime at least once in the next year," and "will die from any cause." Overall, the adolescents provided relatively reasonable estimates of the various outcomes happening to them, with the exception that they tended to overestimate the likelihood of death in the near future. Older children have been found to provide more accurate estimations of their abilities and competence compared to younger children (Desoete & Roeyers, 2006; Lipko, Dunlosky, & Merriman, 2009; Newman, 1984; Schneider, Visé, Lockl, & Nelson, 2000).

Myside bias

Myside bias, another dimension of fluid rationality, refers to the tendency to test hypotheses in a manner that is biased toward one's own opinions (Baron, 1995; Perkins, Farady, & Bushey, 1991; Stanovich, 2011; Toplak & Stanovich, 2003). One factor that sets myside bias apart from some of the other rational thinking components is its typical lack of association with cognitive ability. Stanovich and West (2007, 2008a) examined natural myside bias in an adult sample, asking participants to evaluate a variety of controversial propositions with no implicit or explicit inducements to be objective. No association between natural myside bias and cognitive ability was found.

Toplak et al. (in press) used an argument generation task with a developmental sample to examine the myside bias effect. Participants first indicated their prior belief on whether children should have cell phones. Following this question, they were prompted to give reasons in favor of children having a cell phone, followed by reasons against children having a cell phone. The interviewer prompted participants for additional reasons until no additional reasons were given. As in studies with adults using this paradigm, no explicit cues or instructions were given to set aside one's own prior beliefs in answering the

question. A myside bias effect was found, as participants generated more unique reasons in favor of their own position than unique reasons against their position. This finding is consistent with those obtained using other procedures that examined the unbiased processing of evidence in argument evaluation (Klaczynski & Fauth, 1997; Klaczynski & Gordon, 1996; Klaczynski & Lavallee, 2005; Klaczynski & Narasimham, 1998). Myside bias does not seem to differ much across different developmental levels and has not been associated with cognitive abilities in developmental samples. There is evidence, however, that increased years of university-level education may have a moderating effect on myside bias (Toplak & Stanovich, 2003).

Open-minded and objective reasoning styles

Several studies have examined developmental differences with paradigms that necessitate open-minded or objective reasoning in order to evaluate evidence. Examples include paradigms in which participants must differentiate fact from opinion, recognize the validity or invalidity of informal arguments, and recognize contradictions. Overall, several studies suggest that older participants outperform younger participants: older participants were better able to recognize when data were sufficient for making valid causal inferences, or when independent variables were not associated (Kuhn, Phelps, & Walters, 1985); they were more skilled in considering the risks and benefits in hypothetical dilemmas (Halpern-Felsher & Cauffman, 2001), and generating counterexamples (De Neys & Everaerts, 2008, but see Kuhn, 1991). Although extensively studied with adults, there has been considerably less research examining belief flexibility, actively open-minded thinking, and the tendency to fully process information (such as Need for Cognition and Typical Intellectual Engagement) in children.

Prudent attitude toward the future

A prudent attitude toward the future shifts the focus from “here and now” to consideration of future outcomes. Several procedures have been used to measure attitudes toward the future, including temporal discounting, future orientation scales, and delay of gratification tasks. These tasks typically ask participants to choose between smaller immediate rewards or substantially larger delayed rewards. Selection of the larger delayed rewards is typically scored as more optimal (Ainslie, 1975; Kirby, 1997).

A number of developmental studies have found that increasing age is associated with less extreme temporal discounting (Green et al., 1994; Prencipe et al., 2006; Steinberg et al., 2009) and a more future orientation (Steinberg et al., 2009). Cognitive ability tends to be positively associated with a reduction in temporal discounting (Shamosh & Gray, 2008; Shamosh et al., 2008), and longitudinal studies have reported that positive long-term cognitive, educational, and career outcomes can be predicted from an early willingness to delay rewards (Mischel et al., 2011; Prencipe et al., 2006; Rodriguez, Mischel, & Shoda, 1989; Steinberg et al., 2009).

Emotion regulation related to reward; sensitivity to emotions

The Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994) has been widely used to assess this last dimension listed under fluid rationality in Table 2.1. A participant taking the IGT selects 100 cards, one at a time, from four 50-card decks. Each card is associated with various rewards and penalties that are revealed once the card is selected. Each deck is either advantageous or disadvantageous in terms of the eventual net rewards and penalties that will accrue over the course of several card selections. Poor performance on the IGT has been attributed to a dysregulation of somatic markers that hinders the learning of a deck's relative advantageous or disadvantageous nature as the decks are initially haphazardly sampled (Damasio, 1994, 1996, 1999). Namely, individuals who perform poorly on this task purportedly have weaker somatic or physiological cues to guide risky choices (Damasio, 1994, 1996, 1999).

Older participants generally outperform younger participants on the IGT (Crone & van der Molen, 2004; Garon & Moore, 2004; Hooper, Luciana, Conklin, & Yarger, 2004; Hongwanishkul, Happaney, Lee, & Zelazo, 2005; Lamm et al., 2006; Overman et al., 2004; Prencipe et al., 2006; Steinberg, 2010). Positive associations have also been reported between IGT performance and cognitive ability measures, but these associations tend to be small to modest, indicating that considerable variability in performance on the IGT is not captured by current measures of executive function and intelligence (Toplak, Sorge, Benoit, West, & Stanovich, 2010).

Crystallized rationality: crystallized facilitators

Crystallized rationality is the second major component of rational thinking. It is composed of mindware (Perkins, 1995), a term that refers to rules, knowledge, procedures, and strategies that can be used in decision making. As discussed previously, crystallized rationality is separated into crystallized facilitators and crystallized inhibitors. The former category refers to declarative knowledge that can assist rational thinking: understanding probability and statistics, practical numeracy, knowledge of scientific reasoning, and financial and economic thinking.

Probabilistic and statistical reasoning

Older participants typically do better than younger participants on a broad set of measures that assess probabilistic and statistical reasoning. For example, older participants typically do better on gambler's fallacy and sample-size problems (Chiesi, Primi, & Morsanyi, 2011), probability adjustment tasks (Falk & Wilkening, 1998), and class inclusion and Piagetian probability tasks (Agnoli, 1991; Kreidler & Kreidler, 1986).

Tversky and Kahneman's (1983) classic conjunction problem presented adult participants with a stereotypical description of a student named Linda who

would have seemed to be much more likely to become an active feminist than a bank teller. A majority of adults given this problem make an error by judging the likelihood of the conjunction of two possibilities (“Linda is a bank teller and is active in the feminist movement”) as being more likely than the individual possibilities (“Linda is a bank teller”). The findings for conjunction problems with developmental samples have been mixed: the conjunction effect has sometimes been smaller for older children (Chiesi et al., 2011), sometimes been smaller for younger children (Davidson, 1995; Fishbein & Schnarch, 1997; Morsanyi & Handley, 2008), and sometimes not differed with age (Klaczynski, 2001). Possibly relevant to the latter finding, the conjunction effect has been shown to be relatively independent of individual differences in intelligence when studied using between-subject designs (Stanovich & West, 2008b). All conjunction-effect problems depend on participants having well-instantiated knowledge of particular stereotypes, and the extent to which the mixed developmental finding may reflect differential knowledge of the relevant stereotypes is unknown (Stanovich et al., 2011).

Practical numeracy is another domain of helpful mindware, and refers to competence in using and applying mathematical knowledge to real-world situations. Adults who lack basic proficiency in this type of knowledge have been shown to be less accurate in comprehending medically related information and to make poorer health-related decisions (Reyna & Brainerd, 2007).

Knowledge of scientific reasoning

The development of knowledge of scientific reasoning has been extensively studied (see Table 2.1). Scientific thinking involves knowledge about how to test and revise theories, design proper controls for extraneous variables, and objectively evaluate evidence (Zimmerman, 2007). Understanding the need for experimental controls, such as isolating variables and inclusion of control conditions, increases with age in children (Klahr, Fay, & Dunbar, 1993; Klahr & Nigam, 2004; Masnick & Morris, 2008; Tschirgi, 1980). Older children are also more likely to take covariation among variables into account and resist inappropriate causal inferences (Klaczynski, 2001; Koslowski, Condry, Sprague, & Hutt, 1996; Koslowski, Okagaki, Lorenz, & Umbach, 1989; Richardson, 1992).

Financial literacy and economic thinking

The rational thinking domain of financial literacy and economic thinking is increasingly important in our modern society. This domain of crystallized facilitators involves declarative knowledge of basic facts about how financial institutions operate (such as, stocks versus savings accounts), knowledge of economics concepts (such as, supply and demand), recognizing sunk costs, and understanding zero-sum games. The pitfall of honoring sunk costs involves persisting in an activity with negative expected value because a significant investment has already been made (Arkes & Ayton, 1999; Arkes & Blumer, 1985).

Commons dilemmas are well known and are often studied using variations of the Prisoner's Dilemma paradigm, where a choice to cooperate is pitted against a choice to compete.

In the limited work that has been done using these paradigms with developmental samples, older participants have demonstrated higher levels of financial literacy and more economic thinking than younger participants (Mandell, 2009; Thompson & Siegler, 2000). Empirical findings on sunk cost effects with developmental samples have been more mixed. Sometimes older participants have been found to honor sunk costs more often than younger participants (Klaczynski, 2001; Strough, Mehta, McFall, & Schuller, 2008) and sometimes no developmental effects have been found (Baron, Granato, Spranca, & Teubal, 1993; Morsanyi & Handley, 2008). Older children have been found to be somewhat more likely to cooperate in multiple sessions of Prisoner's Dilemma games than younger children (Brady et al., 1983; Matsumoto, Haan, Yabrove, Theodorou, & Carney, 1986).

Crystallized rationality: crystallized inhibitors

Mindware can also involve crystallized inhibitors that hinder rationality by subverting our goals or by being composed of dysfunctional beliefs (Stanovich, 2011). For example, adults who have fewer superstitious beliefs are better able to evaluate arguments in an unbiased manner (Stanovich & West, 1997). Superstitious thinking is also associated with such maladaptive real-world behaviors as pathological gambling (Stanovich, 2011; Toplak, Liu, MacPherson, Toneatto, & Stanovich, 2007). Overall, relevant developmental research in the domain of crystallized inhibitors has been sparse. Developmental research has found negative associations between superstitious thinking and both age and cognitive abilities (Kokis et al., 2002; Preece & Baxter, 2000; Toplak et al., in press). These beliefs often have adverse consequences (Stanovich, 2009). The belief that one possesses "good luck" may inhibit rational goal pursuit and the development of necessary talents. It might displace more efficacious behavioral strategies.

Developmental of rational thinking: conclusions

To summarize, Figure 2.1 provides an overview of our taxonomy for assessing the development of rational thinking. Table 2.1 provides examples showing how all the major dimensions of rational thinking have been operationalized in the developmental literature. Given the complexity of the framework and characteristics of the developmental studies themselves, no overly broad generalizations about the development of rational thinking should be made. Currently, some developmental patterns are more clear than others. For example, research with belief bias syllogisms have consistently shown that children's performance improves with age, which is consistent with the positive correlations that are found between belief bias syllogisms performance and cognitive ability in adults (Stanovich &

West, 2008b). The picture with respect to many other developmental differences in the table (framing effects, for example) is much less clear.

Understanding the developmental trajectories of all of the components of rational thinking will require enormous scientific effort, much of which is still ahead of us. Because the operational measures that are used are often borrowed from adult studies, it is crucial that great care be taken to ensure that the adapted measures are age-appropriate for younger participants (Stanovich et al., 2011). As illustrated by the sampling of studies described in Table 2.1, there has been some initial progress in understanding the development of each rational thinking component. The listing of measurement paradigms and the corresponding sampling of findings in Table 2.1 highlight the fact that rational thinking in children is both measurable and, importantly, separable from cognitive ability as it is currently measured.

Author note

Preparation of this chapter was supported by grants from the Social Sciences and Humanities Research Council of Canada to Maggie Toplak and from the John Templeton Foundation to Keith Stanovich and Richard West. The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the John Templeton Foundation.

References

- Ackerman, P. L. (1996). A theory of adult development: Process, personality, interests, and knowledge. *Intelligence, 22*, 227–257.
- Acredolo, C., O'Connor, J., Banks, L., & Horobin, K. (1989). Children's ability to make probability estimates: Skills revealed through application of Anderson's functional measurement methodology. *Child Development, 60*, 933–945.
- Agnoli, F. (1991). Development of judgmental heuristics and logical reasoning: Training counteracts the representativeness heuristic. *Cognitive Development, 6*, 195–217.
- Ainslie, G. (1975). Specious reward: A behavioral theory of impulsiveness and impulse control. *Psychological Bulletin, 82*(4), 463–496.
- Anderson, M. (2005). Marrying intelligence and cognition: A developmental view. In R. J. Sternberg & J. E. Pretz (Eds.), *Cognition and intelligence* (pp. 268–287). New York: Cambridge University Press.
- Arkes, H. R., & Ayton, P. (1999). The sunk cost and Concorde effects: Are humans less rational than lower animals? *Psychological Bulletin, 125*, 591–600.
- Arkes, H. R., & Blumer, C. (1985). The psychology of sunk cost. *Organizational Behavior and Human Decision Processes, 35*, 124–140.
- Baron, J. (1995). Myside bias in thinking about abortion. *Thinking & Reasoning, 1*, 221–235.
- Baron, J. (2008). *Thinking and deciding (Fourth Edition)*. Cambridge, MA: Cambridge University Press.
- Baron, J., Granato, L., Spranca, M., & Teubal, E. (1993). Decision making biases in children and early adolescents: Exploratory studies. *Merrill-Palmer Quarterly, 39*, 22–46.

- Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, 50, 7–15.
- Benjamin, D., & Shapiro, J. (2005, February 25). Does cognitive ability reduce psychological bias? *Journal of Economic Literature*, J24, D14, C91.
- Bernard, M. E., & Cronan, F. (1999). The child and adolescent scale of irrationality: Validation data and mental health correlates. *Journal of Cognitive Psychotherapy: An International Quarterly*, 13, 121–132.
- Bjorklund, D. F. (2004). *Children's thinking: Cognitive development and individual differences*. Stamford, CT: Wadsworth.
- Bolton, D., Dearsley, P., Madronal-Luque, R., & Baron-Cohen, S. (2002). Magical thinking in childhood and adolescence: Development and relation to obsessive compulsion. *British Journal of Developmental Psychology*, 20, 479–494.
- Brady, J. E., Newcomb, A. F., & Hartup, W. W. (1983). Context and companion's behavior as determinants of cooperation and competition in school age children. *Journal of Experimental Child Psychology*, 36, 396–412.
- Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies*. Cambridge: Cambridge University Press.
- Cattell, R. B. (1963). Theory for fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology*, 54, 1–22.
- Cattell, R. B. (1998). Where is intelligence? Some answers from the triadic theory. In J. J. McArdle & R. W. Woodcock (Eds.), *Human cognitive abilities in theory and practice* (pp. 29–38). Mahwah, NJ: Erlbaum.
- Chen, H., & Volpe, R. P. (1998). An analysis of personal financial literacy among college students. *Financial Services Review*, 7(2), 107–128.
- Chiesi, F., Primi, C., & Morsanyi, K. (2011). Developmental changes in probabilistic reasoning: The role of cognitive capacity, instructions, thinking styles, and relevant knowledge. *Thinking & Reasoning*, 17(3), 315–350.
- Cohn, L. D., Macfarlane, S., Yanez, C., & Imai, W. K. (1995). Risk-perception: differences between adolescents and adults. *Health Psychology*, 14, 217–222.
- Crone, E. A., & van der Molen, M. W. (2004). Developmental changes in real life decision making: Performance on a gambling task previously shown to depend on the ventromedial prefrontal cortex. *Developmental Neuropsychology*, 25, 251–279.
- Damasio, A. R. (1994). *Descartes' error*. New York: Putnam.
- Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society (London)*, 351, 1413–1420.
- Damasio, A. R. (1999). *The feeling of what happens*. New York: Harcourt Brace.
- Davidson, D. (1995). The representativeness heuristic and the conjunction fallacy effect in children's decision making. *Merrill-Palmer Quarterly*, 41, 328–346.
- Dawes, R. M. (1998). Behavioral decision making and judgment. In D. T. Gilbert, S. T. Fiske & G. Lindzey (Eds.), *The handbook of social psychology (Vol. 1)* (pp. 497–548). Boston: McGraw-Hill.
- De Neys, W., & Everaerts, D. (2008). Developmental trends in everyday conditional reasoning: The retrieval and inhibition interplay. *Journal of Experimental Child Psychology*, 100, 252–263.
- De Neys, W., & Van Gelder, E. (2009). Logic and belief across the lifespan: The rise and fall of belief inhibition during syllogistic reasoning. *Developmental Science*, 12(1), 123–130.
- De Neys, W., & Vanderputte, K. (2011). When less is not always more: Stereotype knowledge and reasoning development. *Developmental Psychology*, 47, 432–441.

- Deary, I. J. (2001). *Intelligence: A very short introduction*. Oxford: Oxford University Press.
- Denes-Raj, V., & Epstein, S. (1994). Conflict between intuitive and rational processing: When people behave against their better judgment. *Journal of Personality and Social Psychology*, *66*, 819–829.
- Desoete, A., & Roeyers, H. (2006). Metacognitive macroevaluations in mathematical problem solving. *Learning and Instruction*, *16*, 12–25.
- Donkers, B., Melenberg, B., & van Soest, A. (2001). Estimating risk attitudes using lotteries: A large sample approach. *Journal of Risk and Uncertainty*, *22*, 165–195.
- Evans, J. St. B. T., & Perry, T. (1995). Belief bias in children's reasoning. *Cahiers de Psychologie Cognitive*, *14*, 103–115.
- Evans, J. St. B. T., Barston, J., & Pollard, P. (1983). On the conflict between logic and belief in syllogistic reasoning. *Memory & Cognition*, *11*, 295–306.
- Facione, P. (1990). *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction (Executive Summary of the Delphi Report)*. La Cruz, CA: California Academic Press.
- Falk, R., & Wilkening, F. (1998). Children's construction of fair chances: Adjusting probabilities. *Developmental Psychology*, *34*, 1340–1357.
- Fischhoff, B., Parker, A. M., de Bruin, W., Downs, J., Palmgren, C., Dawes, R., & Manksi, C. F. (2000). Teen expectations for significant life events. *Public Opinion Quarterly*, *64*, 189–205.
- Fishbein, E., & Schnarch, D. (1997). The evolution with age of probabilistic, intuitively-based misconceptions. *Journal for Research in Mathematics Education*, *28*, 96–105.
- Foltz, C., Overton, W. F., & Ricco, R. (1995). Proof construction: Adolescent development from inductive to deductive problem-solving strategies. *Journal of Experimental Child Psychology*, *59*, 179–195.
- Fong, G. T., Krantz, D. H., & Nisbett, R. E. (1986). The effects of statistical training on thinking about everyday problems. *Cognitive Psychology*, *18*, 253–292.
- Frederick, S. (2005). Cognitive reflection and decision making. *Journal of Economic Perspectives*, *19*, 25–42.
- Furlan, S., Agnoli, F., & Reyna, V. F. (2012). Children's competence or adults' incompetence: Different developmental trajectories in different tasks. *Developmental Psychology*. Advance online publication.
- Garon, N., & Moore, C. (2004). Complex decision-making in early childhood. *Brain and Cognition*, *55*, 158–170.
- Geary, D. C. (2005). *The origin of the mind: Evolution of brain, cognition, and general intelligence*. Washington, DC: American Psychological Association.
- Green, L., Fry, A. F., & Myerson, J. (1994). Discounting of delayed rewards: A life-span comparison. *Psychological Science*, *5*(1), 33–36.
- Halpern-Felsher, B. L., & Cauffman, E. (2001). Costs and benefits of a decision: Decision-making competence in adolescents and adults. *Applied Developmental Psychology*, *22*, 257–273.
- Handley, S. J., Capon, A., Beveridge, M., Dennis, I., & Evans, J. St. B. T. (2004). Working memory, inhibitory control and the development of children's reasoning. *Thinking & Reasoning*, *10*, 175–195.
- Hongwanishkul, D., Happaney, K. R., Lee, W. S. C., & Zelazo, P. D. (2005). Assessment of hot and cool executive function in young children: Age-related changes and individual differences. *Developmental Neuropsychology*, *28*, 617–644.

- Hooper, C. J., Luciana, M., Conklin, H. M., & Yarger, R. S. (2004). Adolescents' performance on the Iowa Gambling Task: Implications for the development of decision making and ventromedial prefrontal cortex. *Developmental Psychology, 40*, 1148–1158.
- Hooper, S. R., & Layne, C. C. (1983). The common belief inventory for students: A measure of rationality in children. *Journal of Personality Assessment, 47*, 85–90.
- Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. *Acta Psychologica, 26*, 1–23.
- Horn, J. L., & Noll, J. (1997). Human cognitive capabilities: Gf-Gc theory. In D. Flanagan, J. Genshaft & P. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 53–91). New York: Guilford Press.
- Jacobs, E., & Potenza, M. (1991). The use of judgment heuristics to make social and object decisions: A developmental perspective. *Child Development, 62*, 166–178.
- Kahneman, D. (2011). *Thinking, fast and slow*. New York: Farrar, Straus & Giroux.
- Kahneman, D., & Frederick, S. (2002). Representativeness revisited: Attribute substitution in intuitive judgment. In T. Gilovich, D. Griffin & D. Kahneman (Eds.), *Heuristics and biases: The psychology of intuitive judgment* (pp. 49–81). New York: Cambridge University Press.
- Kahneman, D., & Tversky, A. (1973). On the psychology of prediction. *Psychological Review, 80*, 237–251.
- Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47*, 263–291.
- Kahneman, D., & Tversky, A. (1984). Choices, values, and frames. *American Psychologist, 39*, 341–350.
- Kahneman, D., & Tversky, A. (Eds.). (2000). *Choices, values, and frames*. Cambridge: Cambridge University Press.
- Kirby, K. (1997). Bidding on the future: Evidence against normative discounting of delayed rewards. *Journal of Experimental Psychology: General, 126*(1), 54–70.
- Kirkpatrick, L., & Epstein, S. (1992). Cognitive-experiential self-theory and subjective probability: Evidence for two conceptual systems. *Journal of Personality and Social Psychology, 63*, 534–544.
- Klaczynski, P. A. (2001). Analytic and heuristic processing influences on adolescent reasoning and decision making. *Child Development, 72*, 844–861.
- Klaczynski, P. A., & Fauth, J. (1997). Developmental differences in memory-based intrusions and self-serving statistical reasoning biases. *Merrill-Palmer Quarterly, 43*, 539–566.
- Klaczynski, P. A., & Gordon, D. H. (1996). Self-serving influences on adolescents' evaluations of belief-relevant evidence. *Journal of Experimental Child Psychology, 62*, 317–339.
- Klaczynski, P. A., & Lavalley, K. L. (2005). Domain-specific identity, epistemic regulation, and intellectual ability as predictors of belief-based reasoning: A dual-process perspective. *Journal of Experimental Child Psychology, 92*, 1–24.
- Klaczynski, P. A., & Narasimham, G. (1998). Development of scientific reasoning biases: Cognitive versus ego-protective explanations. *Developmental Psychology, 34*, 175–187.
- Klahr, D., & Nigam, M. (2004). The equivalence of learning paths in early science instruction: Effects of direct instruction and discovery learning. *Psychological Science, 15*(10), 661–667.
- Klahr, D., Fay, A. L., & Dunbar, K. (1993). Heuristics for scientific experimentation: A developmental study. *Cognitive Psychology, 25*, 111–146.

- Kokis, J., Macpherson, R., Toplak, M., West, R. F., & Stanovich, K. E. (2002). Heuristic and analytic processing: Age trends and associations with cognitive ability and cognitive styles. *Journal of Experimental Child Psychology*, 83, 26–52.
- Koslowski, B., Condry, K., Sprague, K., & Hutt, M. (1996). Beliefs about covariation and causal mechanisms – Implausible as well as plausible. Experiment 4. In B. Koslowski, *Theory and evidence: The development of scientific reasoning*. MIT Press: Cambridge, MA.
- Koslowski, B., Okagaki, L., Lorenz, C., & Umbach, D. (1989). When covariation is not enough: The role of causal mechanism, sampling method, and sample size in causal reasoning. *Child Development*, 60, 1316–1327.
- Kreitler, S., & Kreitler, H. (1986). Development of probability thinking in children 5 to 12 years old. *Cognitive Development*, 1, 365–390.
- Kühberger, A. (1998). The influence of framing on risky decisions: A meta-analysis. *Organizational Behavior and Human Decision Processes*, 75, 23–55.
- Kuhn, D. (1991). *The skills of argument*. Cambridge: Cambridge University Press.
- Kuhn, D., Phelps, E., & Walters, J. (1985). Correlational reasoning in an everyday context. *Journal of Applied Developmental Psychology*, 6, 85–97.
- Lamm, C., Zelazo, P. D., & Lewis, M. D. (2006). Neural correlates of cognitive control in childhood and adolescence: Disentangling the contributions of age and executive function. *Neuropsychologia*, 44(11), 2139–2148.
- Levin, I. P., & Hart, S. S. (2003). Risk preferences in young children: Early evidence of individual differences in reaction to potential gains and losses. *Journal of Behavioral Decision Making*, 16, 397–413.
- Levin, I. P., Gaeth, G. J., Schreiber, J., & Lauriola, M. (2002). A new look at framing effects: Distribution of effect sizes, individual differences, and independence of types of effects. *Organizational Behavior and Human Decision Processes*, 88, 411–429.
- Levin, I. P., Weller, J. A., Pederson, A. A., & Harshman, L. A. (2007). Age-related differences in adaptive decision making: Sensitivity to expected value in risky choice. *Judgment and Decision Making*, 2(4), 225–233.
- Li, F., Cao, B., Li, Y., & Li, H. (2009). The law of large numbers in children's diversity-based reasoning. *Thinking & Reasoning*, 15(4), 388–404.
- Lipko, A. R., Dunlosky, J., & Merriman, W. E. (2009). Persistent overconfidence despite practice: The role of task experience in preschoolers' recall predictions. *Journal of Experimental Child Psychology*, 103, 152–166.
- Lubinski, D. (2004). Introduction to the special section on cognitive abilities: 100 years after Spearman's (1904) "General Intelligence, Objectively Determined and Measured". *Journal of Personality and Social Psychology*, 86, 96–111.
- Luce, R. D., & Raiffa, H. (1957). *Games and decisions*. New York: Wiley.
- Mandell, L. (2009). *The financial literacy of young American adults*. Washington, DC: JumpStart Coalition for Personal Financial Literacy.
- Manktelow, K. I. (2004). Reasoning and rationality: The pure and the practical. In K. I. Manktelow & M. C. Chung (Eds.), *Psychology of reasoning: Theoretical and historical perspectives* (pp. 157–177). Hove, England: Psychology Press.
- Markovits, H., & Bouffard-Bouchard, T. (1992). The belief-bias effect in reasoning: The development and activation of competence. *British Journal of Developmental Psychology*, 10, 269–284.
- Markovits, H., & Thompson, V. (2008). Different developmental patterns of simple deductive and probabilistic inferential reasoning. *Memory & Cognition*, 36(6), 1066–1078.

- Markovits, H., Venet, M., Janveau-Brennan, G., Malfait, N., Pion, N., & Vadeboncoeur, I. (1996). Reasoning in young children: Fantasy and information retrieval. *Child Development, 67*, 2857–2872.
- Masnick, A. M., & Morris, B. J. (2008). Investigating the development of data evaluation: The role of data characteristics. *Child Development, 79*(4), 1032–1048.
- Matsumoto, D., Haan, N., Yabrove, G., Theodorou, P., & Carney, C. C. (1986). Preschoolers' moral actions and emotions in prisoner's dilemma. *Developmental Psychology, 22*, 663–670.
- Maule, J., & Villejoubert, G. (2007). What lies beneath: Reframing framing effects. *Thinking & Reasoning, 13*, 25–44.
- Mischel, W., Ayduk, O., Berman, M. G., Casey, B. J., Gotlib, I. H., Jonides, J., et al. (2011). 'Willpower' over the life span: Decomposing self-regulation. *SCAN, 6*, 252–256.
- Morsanyi, K., & Handley, S. J. (2008). How smart do you need to be to get it wrong? The role of cognitive capacity in the development of heuristic-based judgment. *Journal of Experimental Child Psychology, 99*, 18–36.
- Moshman, D., & Franks, B. (1986). Development of the concept of inferential validity. *Child Development, 57*, 153–165.
- Newman, R. S. (1984). Children's numerical skill and judgments of confidence in estimation. *Journal of Experimental Child Psychology, 37*, 107–123.
- Over, D. E. (2004). Rationality and the normative/descriptive distinction. In D. J. Koehler & N. Harvey (Eds.), *Blackwell handbook of judgment and decision making* (pp. 3–18). Malden, MA: Blackwell Publishing.
- Overman, W. H., Frassrand, K., Ansel, S., Trawalter, S., Bies, B., & Redmond, A. (2004). Performance on the Iowa card task by adolescents and adults. *Neuropsychologia, 42*, 1838–1851.
- Pacini, R., & Epstein, S. (1999). The relation of rational and experiential information processing styles to personality, basic beliefs, and the ratio-bias phenomenon. *Journal of Personality and Social Psychology, 76*, 972–987.
- Perkins, D. N. (1995). *Outsmarting IQ: The emerging science of learnable intelligence*. New York: Free Press.
- Perkins, D. N., Farady, M., & Bushey, B. (1991). Everyday reasoning and the roots of intelligence. In J. Voss, D. Perkins & J. Segal (Eds.), *Informal reasoning and education* (pp. 83–105). Hillsdale, NJ: Erlbaum.
- Pillow, B. H. (2002). Children's and adults' evaluation of the certainty of deductive inferences, inductive inferences, and guesses. *Child Development, 73*, 779–792.
- Preece, P. F. W., & Baxter, J. H. (2000). Scepticism and gullibility: The superstitious and pseudo-scientific beliefs of secondary school students. *International Journal of Science Education, 22*(11), 1147–1156.
- Prencipe, A., Kesek, A., Cohen, J., Lamm, C., Lewis, M. D., & Zelazo, P. D. (2006). Development of hot and cool executive function during the transition to adolescence. *Journal of Experimental Child Psychology, 108*, 621–637.
- Rakow, T., & Rahim, S. B. (2010). Developmental insights into experience-based decision making. *Journal of Behavioral Decision Making, 23*(1), 69–82.
- Reyna, V. F., & Brainerd, C. J. (2007). The importance of mathematics in health and human judgment: Numeracy, risk communication, and medical decision making. *Learning and Individual Differences, 17*, 147–159.
- Reyna, V. F., & Ellis, S. (1994). Fuzzy-trace theory and framing effects in children's risky decision making. *Psychological Science, 5*, 275–279.

- Reyna, V. F., & Farley, F. (2006). Risk and rationality in adolescent decision making. *Psychological Science in the Public Interest*, 7, 1–44.
- Richardson, K. (1992). Covariation analysis of knowledge representation: Some developmental studies. *Journal of Experimental Child Psychology*, 53, 129–150.
- Rodriguez, M. L., Mischel, W., & Shoda, Y. (1989). Cognitive person variables in delay of gratification of older children at risk. *Journal of Personality and Social Psychology*, 57, 358–367.
- Savage, L. J. (1954). *The foundations of statistics*. New York: Wiley.
- Schlottmann, A. (2000). Children's judgments of gambles: A disordinal violation of utility. *Journal of Behavioral Decision Making*, 13, 77–89.
- Schlottmann, A. (2001). Children's probability intuitions: Understanding the expected value of complex gambles. *Child Development*, 72, 103–122.
- Schlottmann, A., & Tring, J. (2005). How children reason about gains and losses: Framing effects in judgement and choice. *Swiss Journal of Psychology*, 64(3), 153.
- Schneider, W., Visé, M., Lockl, K., & Nelson, R. O. (2000). Developmental trends in children's memory monitoring: Evidence from a judgment-of-learning task. *Cognitive Development*, 15, 115–134.
- Shamosh, N. A., & Gray, J. R. (2008). Delay discounting and intelligence: A meta-analysis. *Intelligence*, 36, 289–305.
- Shamosh, N. A., DeYoung, C. G., Green, A. E., Reis, D. L., Johnson, M. R., Conway, A. R. A., et al. (2008). Individual differences in delay discounting relation to intelligence, working memory, and anterior prefrontal cortex. *Psychological Science*, 19(9), 904–911.
- Smith, L. (1999). Necessary knowledge in number conservation. *Developmental Science*, 2, 23–27.
- Stanovich, K. E. (2006). Rationality and the adolescent mind. Editorial. *Psychological Science in the Public Interest*, 7, i–ii.
- Stanovich, K. E. (2009). *What intelligence tests miss: The psychology of rational thought*. New Haven, CT: Yale University Press.
- Stanovich, K. E. (2011). *Rationality and the reflective mind*. New York: Oxford University Press.
- Stanovich, K. E., & West, R. F. (1997). Reasoning independently of prior belief and individual differences in actively open-minded thinking. *Journal of Educational Psychology*, 89, 342–357.
- Stanovich, K. E., & West, R. F. (2007). Natural myside bias is independent of cognitive ability. *Thinking & Reasoning*, 13(3), 225–247.
- Stanovich, K. E., & West, R. F. (2008a). On the failure of intelligence to predict myside bias and one-sided bias. *Thinking & Reasoning*, 14, 129–167.
- Stanovich, K. E., & West, R. F. (2008b). On the relative independence of thinking biases and cognitive ability. *Journal of Personality and Social Psychology*, 94, 672–695.
- Stanovich, K. E., Toplak, M. E., & West, R. F. (2008). The development of rational thought: A taxonomy of heuristics and biases. *Advances in Child Development and Behavior*, 36, 251–285.
- Stanovich, K. E., West, R. F., & Toplak, M. E. (2011). The complexity of developmental predictions from dual process models. *Developmental Review*, 31, 103–118.
- Steege, S., & De Neys, W. (2012). Belief inhibition in children's reasoning: Memory-based evidence. *Journal of Experimental Child Psychology*, 112, 231–242.
- Steinberg, L. (2010). A dual systems model of adolescent risk-taking. *Developmental Psychobiology*, 52, 216–224.

- Steinberg, L., Graham, S., O'Brien, L., Woolard, J., Cauffman, E., & Banich, M. (2009). Age differences in future orientation and delay discounting. *Child Development, 80*, 28–44.
- Strough, J., Mehta, C. M., McFall, J. P., & Schuller, K. L. (2008). Are older adults less subject to the sunk-cost fallacy than younger adults? *Psychological Science, 19*, 650–652.
- Thompson, D. R., & Siegler, R. S. (2000). Buy low, sell high: The development of an informal theory of economics. *Child Development, 71*, 660–677.
- Toplak, M. E., & Stanovich, K. E. (2003). Associations between myside bias on an informal reasoning task and amount of post-secondary education. *Applied Cognitive Psychology, 17*(7), 851–860.
- Toplak, M. E., Liu, E., MacPherson, R., Toneatto, T., & Stanovich, K. E. (2007). The reasoning skills and thinking dispositions of problem gamblers: A dual-process taxonomy. *Journal of Behavioral Decision Making, 20*(2), 103–124.
- Toplak, M. E., Sorge, G. B., Benoit, A., West, R. F., & Stanovich, K. E. (2010). Decision-making and cognitive abilities: A review of associations between Iowa Gambling Task performance, executive functions, and intelligence. *Clinical Psychology Review, 30*, 562–581.
- Toplak, M. E., West, R. F., & Stanovich, K. E. (in press). Rational thinking and cognitive sophistication: Development, cognitive ability, and thinking dispositions. *Developmental Psychology*.
- Tschirgi, J. E. (1980). Sensible reasoning: A hypothesis about hypotheses. *Child Development, 51*, 1–10.
- Tullos, A., & Woolley, J. D. (2009). The development of children's ability to use evidence to infer reality status. *Child Development, 80*(1), 101–114.
- Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science, 185*, 1124–1131.
- Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science, 211*, 453–458.
- Tversky, A., & Kahneman, D. (1983). Extensional versus intuitive reasoning: The conjunction fallacy in probability judgment. *Psychological Review, 90*, 293–315.
- Weller, J. A., Levin, I. P., & Denburg, N. L. (2011). Trajectory of risky decision making for potential gains and losses from ages 5 to 85. *Journal of Behavioral Decision Making, 24*, 331–344.
- Zimmerman, C. (2007). The development of scientific thinking skills in elementary and middle school. *Developmental Review, 27*, 172–223.