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Meta-Reasoning:

Shedding Meta-Cognitive Light on Reasoning Research

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In this chapter, we argue that understanding the processes that underlie reasoning, problem solving, and decision-making[1] can be informed by understanding the metacognitive processes that monitor and control them. Our goal is to show that a metacognitive analysis applies to a wide range of reasoning tasks and theoretical perspectives, including Dual Process Theories, Mental Models Theory (Johnson-Laird & Byrne, 1991), Fast and Frugal Heuristics (e.g., Gigerenzer, Todd, and the ABC Group, 1999), probabilistic models of reasoning (Oaksford & Chater, 2007) and a wide variety of problem-solving paradigms. We hope that the range of examples that we provide will allow the reader to usefully extend these principles even further, to theories of analogy, induction, causal inference, etc.

Metacognition is often defined as “thinking about thinking”, which implies a reflective, introspective set of processes by which we evaluate and alter our approach to the world. In contrast, most theorists conceive of metacognitive processes as those that are responsible for monitoring and controlling our ongoing cognitive processes (Nelson & Narens, 1990). They are thought to be running in the background and monitoring the success of ongoing cognitive processes (such as reading, remembering, reasoning) in much the same way as a thermostat monitors the temperature of the air. Like the thermostat, which can send a signal to the furnace to start or terminate functioning, metacognitive processes are assumed to have an analogous control function over the initiation or cessation of mental effort.

From the point of view of reasoning research, understanding these processes is important because there is compelling evidence from other domains (e.g., memorization - Metcalfe & Finn,

[1] These are all referred to collectively under the umbrella term “reasoning”.

2011 and reading comprehension – Thiede, Anderson, & Therriault, 2003) that these monitoring processes are the input to control processes, which then allocate attentional and working memory resources. By extension, therefore, we would expect analogous control processes in reasoning, problem-solving, and decision-making tasks. Equally important is the evidence that the processes that monitor performance are often based on aspects of said performance that may be irrelevant to achieving good outcomes. Thus, control processes may misdirect or prematurely terminate processing based on poorly calibrated input cues. We argue that understanding the factors that inform these monitoring processes is necessary to understanding the outcome of any reasoning endeavor and for improving reasoners' allocation of resources.

Metacognition and reasoning theories

Implicit to most reasoning theories is the inclusion of a metacognitive component, namely the assumption that reasoners terminate their work on a problem either because they don't know the answer or they are satisfied with the solution (see Evans, 2006 for a discussion of satisficing). This, of course, then raises the question of when and on what basis reasoners become satisfied with their answer or decide that they don't know the answer, which is the goal of the current chapter. Stanovich (2009) was more explicit than most theorists in his argument regarding the need to separate reasoning per se from monitoring and control processes; the latter, he argued, form part of the "reflective mind", which represents individual dispositions to engage analytic thinking. Our analysis, whilst in the same spirit, aims to offer a detailed theoretical framework of the metacognitive mechanisms that continuously monitor and control ongoing cognitive processes.

An initial framework for understanding monitoring and control processes was developed in the context of dual process theories (Thompson, 2009; Thompson et al., 2011). This family of theories assumes that reasoning and decision-making are mediated by two qualitatively different sets of processes: autonomous Type 1 processes and working-memory demanding Type 2 processes (Evans, this volume; see Evans & Stanovich, 2013, for a review). The dual process explanation for many of the classic heuristics and biases derives from the fact that the former processes are faster and form a default response based on heuristic cues such as availability, representativeness, belief, etc.; more deliberate, effortful, time consuming, and working memory demanding Type 2 processes may or may not be engaged to find an alternative solution

(Kahneman, 2011). A crucial issue for this view is to explain when and why these more effortful processes are, or are not engaged.

Thompson (2009) argued that this was essentially a metacognitive question and provided an analysis that was grounded in the rich metacognitive literature (for a similar view, see Fletcher & Carruthers, 2012). According to her framework, Type 1 processes have two outputs: The cognitive output derived from Type 1 processes and the metacognitive output in the form of a Feeling of Rightness (FOR) that accompanies that answer. In this view, the FOR is a monitoring process that mediates the probability of Type 2 engagement: Low FORs are a signal that the answer needs further analysis, whereas a strong FOR is a signal that this is not needed (Thompson et al., 2011; Thompson et al., 2013; Thompson & Johnson, 2014).

However, there have been challenges to the processing assumptions of dual process theories, which might lead some researchers to think that the metacognitive analysis proposed above has limited scope. One such challenge is to the serial processing assumption implied by the default-interventionist architecture described above (Evans, 2007). For example, De Neys (2014) and others (Sloman, 2002) argue that belief-based and logical processes are engaged simultaneously. When they produce conflicting outputs, analytic processes may or may not be engaged to resolve the conflict (De Neys & Bonnefon, 2013). However, regardless of whether one assumes sequential or parallel processes, one must still be able to explain how the conflict is detected and under what circumstances analytic processes are engaged to resolve it; this is an essentially metacognitive question.

A second challenge concerns the distinction between Type 1 and Type 2 processes (Kruglanski & Gigerenzer, 2011), with many theorists arguing that there is only a single type of process that exists on a continuum of speed and complexity (Osman, 2004). We argue that regardless of whether one assumes that Type 1 and Type 2 processes are qualitatively different, the fact that some answers are produced more quickly than others (Evans & Curtis Holmes, 2005; Finucane , Alhakami, Slovic, & Johnson, 2000; Markovits, Brunet, Thompson & Brisson, 2013) means that there is potential for a reasoner to change their initial answer via deliberate analysis. It does not matter whether one assumes that the fast and the slow answer are delivered by qualitatively different processes, the fact that the initial answer may be changed invites the question of when and under what circumstances the answer is changed or kept. It also invites an explanation for the length of time the reasoner spends deliberating as well as the variables that determine how satisfied she is with the final answer. Again, these are fundamentally metacognitive questions.

A case in point is the well-known Mental Models theory (Johnson-Laird & Byrne, 2002, Johnson-Laird, Goodwin, & Khemlani, this volume). This is a theory of how people represent information in a problem space, and how those representations afford inferences about that information. A key assumption of the theory is that people often form an incomplete representation of the problem space, which can be, but which is not always, fleshed out. For example, consider the following pair of premises:

Some of the Artists are Beekeepers

All of the Chemists are Artists.

What follows?

According to Mental Model theory, reasoners construct a model that integrates the premise information and then draw a conclusion from it. For example, the following notation describes a mental representation of the premises that supports the conclusion that all of the beekeepers are chemists:

Chemist	artist	beekeeper
Chemist	artist	beekeeper
Chemist	artist	

There is, however, another way to represent the premises that undermines that conclusion:

		Beekeeper
Chemist	artist	beekeeper
Chemist	artist	beekeeper
Chemist	artist	

Consequently, the conclusions that reasoners draw are determined, at least in part, by whether they are content with their initial answer or whether they search for an alternative. Thus, monitoring and control processes are key for understanding why and when reasoners are content with their initial representations, and the conditions that lead them to expend the necessary effort to supplement it.

Similarly, several theories of reasoning posit that the search for counter-examples to a putative conclusion plays a crucial role in reasoning outcomes (e.g., Cummins, Lubart, Alksnis,

& Rist, 1991; Markovits, 1986; Thompson, 2000); again, the goal is to understand when and why reasoners initiate or fail to initiate such a search. Across a wide spectrum of tasks and paradigms, therefore, a complete understanding of the processes that operate therein requires us to understand when an initial response is deemed adequate and when further reasoning is undertaken. In sum, we argue that no theory of reasoning is complete without understanding the metacognitive processes by which reasoning processes are engaged, formulated, and terminated.

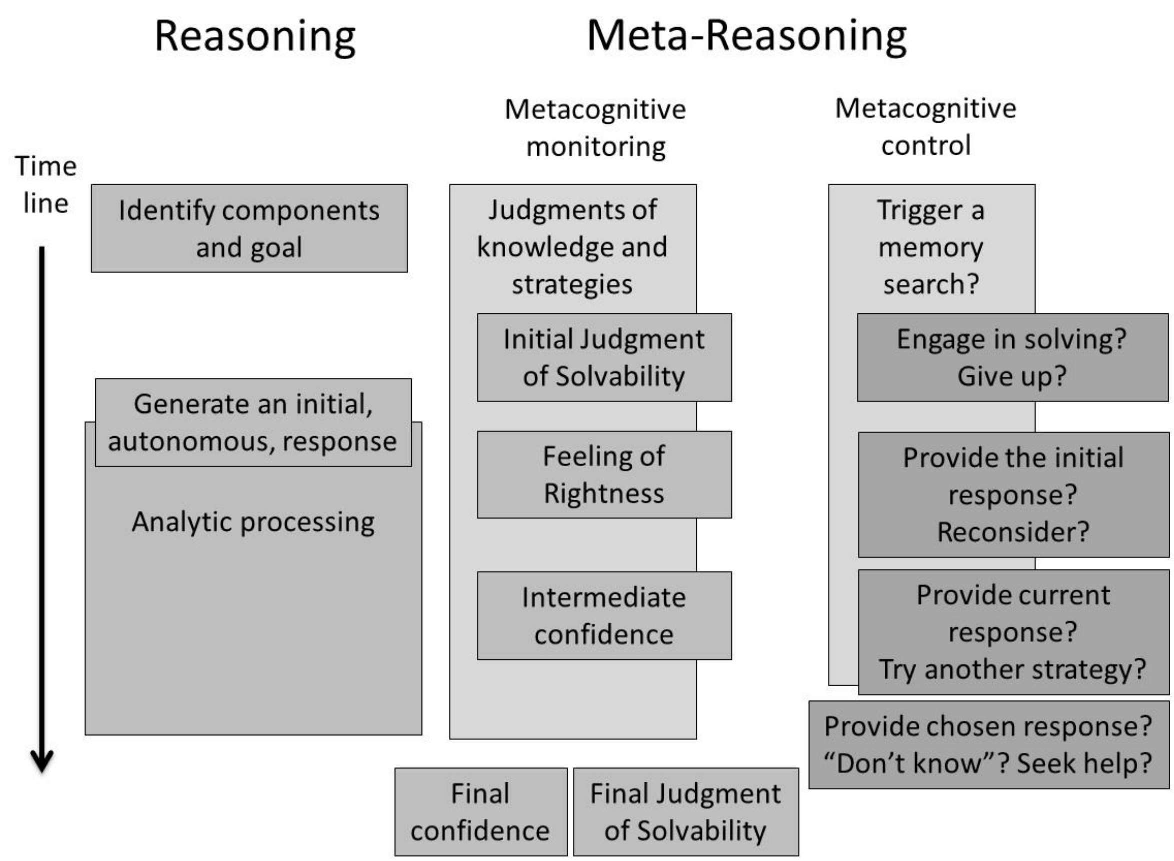

Figure 1. Main reasoning and Meta-Reasoning components presented on a schematic time line.

1. *The Meta-Reasoning framework*

Historically, metacognitive research has been carried out in the context of memory research, and has mostly focussed on the processes that monitor and control learning and retrieval from memory (see Bjork, Dunlosky, & Kornell, 2013, for a review). Typical tasks in Meta-Memory studies involve memorizing paired associates (e.g., King – Sofa) and answering general knowledge questions based on semantic (e.g., In what year did a man walk on the moon for the first time?) or episodic memory (e.g., What did the woman in a blue shirt held in her hand?). Monitoring of memorizing is measured by Judgments of Learning (JOLs), which reflect the learners' estimate of the probability they will recall the item in a subsequent test. The typical control decision studied with this task is allocation of study time. Study time is measured from the pair's presentation till the decision to move on to the next pair. In question answering, the relevant monitoring process is confidence—self-assessment of the chance of each provided answer to be correct. Answering time is measured from question presentation till the decision to move on to the next question. Empirical evidence establishes the causal link between the monitoring and control decisions (Metcalfe & Finn, 2008; Thiede et al., 2003).Triangulating response time, the relevant monitoring type, and actual success in the task, allows delving into the processes that underlie effort regulation (e.g., Ackerman & Leiser, 2014; Undorf & Erdfelder, 2015; Weber & Brewer, 2006).

Many studies have demonstrated that metacognitive monitoring of all types are sensitive to heuristic cues (Koriat, 1997). For instance, retrieval fluency—the ease with which an answer is retrieved—creates a subjective sense of confidence, even when actual performance may be either unrelated or inversely related to it (e.g., Benjamin, Bjork, Schwartz, 1998; Rhodes & Castel, 2008). In addition to relying on heuristic cues that may be misleading, people also underweight factors that consistently affect performance. We know, for example, that repeated rehearsal enhances learning, however, a more effective strategy is repeated testing. In addition, instructions may guide learners to use effective strategies (e.g., imagining words and the relation between them). In all these cases, the pronounced benefit in performance is underestimated in learners' JOLs and confidence judgments (e.g., Karpicke & Roediger, 2008; Koriat, Sheffer, & Ma'ayan, 2002; Rabinowitz, Ackerman, Craik, & Hinchley, 1982). Similarly, people underestimate the impact of forgetting on their ability to recall information, predicting similar recall performance for a test to be taken immediately after studying and one that would take place after a week of retention (Koriat, Bjork, Sheffer, & Bar, 2004).

Recently, we proposed a Meta-Reasoning framework (Ackerman & Thompson, 2015), which extends the metacognitive conceptualization to the domain of reasoning (see Figure 1). In particular, we outlined several ways in which Meta-Reasoning processes share features with their Meta-Memory counterparts. For example, the monitoring of reasoning processes relies on some of the same heuristic cues shared with memory processes. Specifically, reasoners have been found to rely on answer fluency, i.e., the ease with which a solution comes to mind, and the familiarity of the material being reasoned about (e.g., Markovits, Thompson, & Brisson, 2014; Thompson et al., 2013; Topolinski & Reber, 2010; Vernon & Usher, 2003). Understanding these cues is at least as important in reasoning research as in memory research: Reasoning tasks tend to be difficult and, in many cases, describe situations for which there is no single correct answer. Thus, reasoners likely have few other ways to assess the proficiency or accuracy of their reasoning other than to rely on heuristic cues.

These cues have also been found to regulate reasoners' investment of effort, as measured by whether they reconsider an initially produced solution, how much time they allocate to the task, and the decision to provide a concrete solution rather than a "don't know" response (Ackerman, 2014; Reder & Ritter, 1992; Thompson et al., 2011; 2013). However, as is the case in the Meta-Memory literature, these heuristic cues are not always well calibrated with actual reasoning performance (see Ackerman & Thompson, 2015, for a review). In both domains, and particularly for challenging tasks, the correlation between confidence and accuracy of performance may even be zero (Prowse Turner & Thompson, 2009; Shynkaruk & Thompson, 2006). On simple tasks, the correlation is modest (Thompson et al., 2011), but cues such as fluency continue to influence confidence, even when correct and incorrect solutions are analysed separately (Ackerman & Zalmanov, 2012). The potential consequences of misinformed monitoring is misled control processes, such as misallocated resources, poor strategy selection, terminating one's answer search prematurely, etc.

Although Meta-Memory research is a good starting point for understanding Meta-Reasoning processes, we also argued for the need to study Meta-Reasoning processes in their own right. For example, although the monitoring of both reasoning and memory is cue based, there is evidence to suggest that some cues, such as perceptual fluency, act differently in the two domains. Specifically, when memorizing, people judge easy-to-read and hard-to-read items to be equally memorable, even though actual learning is better with hard-to-read fonts (Sungkhasettee, Friedman, & Castel, 2011). In contrast, the difficulty of reading reasoning problems affects neither their judged nor actual degree of difficulty (Meyer et al., 2015; Thompson et al., 2013), despite earlier indications that it might enhance the chance for success with this task as well (Alter, Oppenheimer, Epley, & Eyre, 2007). Moreover, most reasoning processes involve more complex processing than memorizing or answering a knowledge questions (Funke, 2010). It is therefore reasonable to assume that the complexity of the task affects the complexity of the metacognitive processes that are involved in monitoring and control. Thus, as we outline below, the Meta-Reasoning framework has great potential to add to our understanding of how reasoners allocate their mental resources and to suggest fruitful avenues for subsequent research.

2. Metacognitive control decisions

2.1. Initiating analytic thinking

In our Meta-Reasoning framework (Ackerman & Thompson, 2015), we identified two metacognitive monitoring processes that may trigger analytic thought: Judgments of Solvability and the FOR (see Figure 1). The FOR, as described above, monitors an initial response to a reasoning problem. It has been found to vary as a function of the fluency with which the answer is produced, amongst other cues (Markovits, et al., 2014; Thompson et al, 2011; Thompson et al., 2013). FORs are weakened by variables such as the presence of conflicting answers (Thompson & Johnson, 2014) and by the presence of unfamiliar terms in the problems (Markovits et al., 2015). The JOS, in contrast, was postulated to occur before solving begins and to reflect an estimate of the probability of successfully finding a solution; it is most relevant to situations where an immediate answer to a problem does not come to mind. Much less is known about JOS than about FOR. The initial indication is that they are prone, like other monitoring processes, to relying on heuristic cues (Ackerman & Beller, under review, see details below; Topolinksi, 2014). We speculate that the initial Judgment of Solvability is related to the decision to attempt solving at the first place, as well as to the length of time that the respondent persist with solving attempts, once the process is initiated.

2.2. Terminating analytic thinking

In addition to initiating analytic thinking, a second important control process concerns the decision to terminate thinking about a problem. There are at least two bases for disengaging with a problem: a) the current state of affairs is considered satisfactory so that no more resources needed to be invested, and b) there is no reasonable chance of finding the correct solution, so that any further time devoted to the task would be wasted. Here, the reasoner could either guess, or give up (e.g., “I don’t know” response); alternatively, they may generate a response consistent with their incomplete processing, presumably with low confidence, or default to a heuristic answer (e.g., beliefs) if one was available (Quayle & Ball, 2000). Our discussion below reflects the fact that the former has been studied much more than the latter (see Ackerman, 2014). We consider two monitoring types as underlying termination decisions: FOR and intermediate confidence, which differ in terms of when they occur (see Figure 1): FOR is used to monitor an initial answer, while intermediate confidence keeps track of reasoning progress and feeds the decision to terminate it. In a dual process framework, the FOR monitors Type 1 processes and intermediate confidence monitors Type 2 processes. Final confidence reflects the assessment of the chance of the chosen solution to be correct.

FOR. A strong FOR is a sign that further analysis is not needed (Thompson et al., 2011; Thompson, Evans, & Campbell, 2014). Evidence for this assertion is obtained using the two-response paradigm developed by Thompson et al. (2011): Reasoners provide an initial, intuitive answer to a problem, often under time pressure, followed by an answer in free-time. The amount of time spent rethinking the answer, as well as the probability that the reasoner changes the initial answer, varies with the strength of the FOR for the initial answer. This relationship has now been observed in a large number of reasoning tasks, ranging from simple to complex.

Moreover, because the FOR is cue-based, the depth of subsequent analysis may not be related to item difficulty. For example, answers that come to mind fluently may do so because they are based on a heuristic process, which produces a strong sense of confidence in incorrect answers (Thompson et al., 2011; Thompson, et al., 2014). Similarly, familiarity is a strong cue to confidence, but is not necessarily diagnostic of problem difficulty (Markovits et al., 2014; Shynkaruk & Thompson, 2006). In other cases, FOR may rightly signal problem difficulty, as when the problem cues conflicting answers (De Neys, Cromheeke, & Osman, 2011; Thompson et al., 2011). The point is that analytic processing is engaged in response to a monitoring process that may or may not reliably track problem difficulty.

Whereas the preceding work was undertaken in a Dual Process context, here we demonstrate the utility of extending a metacognitive analysis to two types of "fast and frugal" decision strategies (e.g., Gigerenzer, Todd, & the ABC Research Group). The first one comes from a theory of syllogistic reasoning developed by Chater and Oaksford (1999). Syllogistic reasoning is a type of logical reasoning in which reasoners are asked to generate (or evaluate) conclusions from two quantified premises, as the "beekeeper" problem above illustrates. Chater and Oaksford proposed that rather than using logical rules or mental models to solve these problems, people rely on simple heuristics based on information gain. The primary heuristic used to generate conclusions to problems such as the "beekeeper" problem is called the "min" heuristic, which mandates reasoners to choose the quantifier of the conclusion to be the same as the least informative premise. In the "beekeeper" example, above, reasoners would look at the two quantifiers (all and some) and choose "some" because is it the least informative. Thus, they would conclude that "some beekeepers are chemists". In their meta-analysis of past data and in a new experiment designed to test this theory, Chater and Oaksford (1999) demonstrated that reasoners did just that.

Whilst Chater and Oaksford (1999) demonstrated the importance of *min* for conclusion generation, Thompson and colleagues demonstrated that the *min* principle also played a role in how reasoners evaluate their confidence in a conclusion (Thompson et al., 2011). Using the two-response paradigm described above, reasoners were asked to evaluate conclusions that were either consistent or inconsistent with the *min* rule. They found that *min* conclusions were processed more fluently (i.e., more quickly) than their non-*min* counterparts and consequently gave rise to stronger FORs. The difference in FORs also had the expected down-stream effect on analytic thinking: problems with *min* conclusions were subject to less re-analysis and fewer answer changes than their non-min counterparts. In other words, using a fast-and-frugal strategy such as *min* may give rise to confidently held responses that were less likely to be re-considered, regardless of whether they were, in fact, logically valid.

Another potential extension of the FOR to fast and frugal heuristics is in experiments that focus on information search. Many termination decisions are posited to be non-compensatory, in that processing is supposed to be terminated whenever a satisfactory answer is found (see Bröder & Newell, 2008; Hillbig, 2010, for reviews). An example is the "take-the-best" heuristic for choosing amongst a set of alternatives (e.g., deciding which car to buy, which university to attend, which of several brands of consumer goods to buy). This heuristic operates in two steps. The first step operates on the recognition principle, which states that if one of the options is recognized and the others are not, then choose that one and search no further. If more than one alternative is recognized, or if recognition does not discriminate amongst alternatives, the second step is to search for discriminative evidence. The search is assumed to compare each alternative along a single feature, beginning with the feature that has the highest validity, and to continue, one feature at a time until one finds a feature that discriminates amongst alternatives. As an example, let us assume that you are in the grocery store to buy yoghurt. If there is only one brand that you recognize, you would choose that one. If, on the other hand, you recognize more than one, you would compare the brands according to the most important criteria, which, for the sake of argument, might be flavour- you want strawberry. If there are several different strawberry yoghurts, you would then compare them on the next most important cues, possibly calorie count. You proceed in such a fashion until one brand stands out from the others. Importantly, your search is assumed to stop when you reach this point and it is assumed that you would not need to compare the alternatives on another dimension, such as price.

Evidence suggests, however, that people do not stop looking for information, even when they have enough information to make a decision (see Bröder & Newell, 2008; Hillbig, 2010 for reviews). In the example above, you might have recognized only one of the products, but nonetheless investigated price and calorie count for several options (e.g., Newell & Shanks, 2003). This is true even when participants have to pay for each additional bit of information and the information obtained is not helpful to making the decision (Newell, Weston, & Shanks, 2003). Why would people continue to pay for objectively useless information? Bröder and Newell (2008) suggested that people need to feel well-informed before making a decision. A metacognitive reframing of this explanation is that people aspire to a certain level of confidence before a decision is reached. That is, they may have reached an initial decision, but the FOR associated with that decision is below their desired level of confidence, so they continue their search. This, of course, raises the question about what signals a strong or weak FOR in the paradigms used to investigate the "take-the-best" heuristic. It also suggests that people are reluctant to commit to a decision until a threshold of confidence has been reached, such that they continue to gather information until that threshold is reached, as is the case for memorizing under the Meta-Memory framework (Nelson & Narens, 1990). Interestingly, the findings described above suggest that confidence varies as a function of the *quantity* of information available, parallel to the accessibility heuristic cue in Meta-Memory research (Koriat, 1995). Another cue recently suggested in the Meta-Memory literature that seems to be relevant here is consistency (Koriat, 2012). Thus, a further question is whether the *consistency* of the gathered information also matters, both in terms of predicting the extent of the search for additional information and the confidence in which the final choice is made.

Intermediate and final confidence. At a first glance, confidence when answering a knowledge question should be similar to confidence regarding a reasoning challenge. However, there are signs that this is not always the case. For instance, Rozenblit and Keil (2002) examined the extent in which people acknowledge their understanding of the way mechanical instruments work (e.g., bicycle, sewing machine). This is important for example for people to decide whether to look for professional help or additional information or use their own reasoning for solving a case of failure (e.g., breakdown of their bicycle gear). They found that people consistently suffer from an illusion of explanatory depth—they think that they understand quite well how these instruments work as long as they think about them at a high level. Not until they are faced with the challenge of writing down a detailed explanation and/or reading an explanation written by an expert, do they realize their ignorance. This illusion is a reasoning bias, which resembles the overconfidence effect observed in many other domains (Dunning, Johnson, Ehrlinger, & Kruger, 2003; Metcalfe, 1998). However, the illusion varies across domains. Rozenblit and Keil (2002) compared the illusion of explanatory depth across various types of knowledge (e.g., capital cities) and procedures (e.g., bake chocolate chip cookies from scratch), and found that the illusion is particularly severe regarding understanding how mechanical instruments and natural phenomena (e.g., how tides occur) work.

To complicate matters somewhat, evidence is beginning to show that the target level of confidence reasoners set is not constant, as is the case for text learning, but decreases as more effort is invested. Ackerman (2014) gave participants compound remote associate problems, in which the goal is to find one word that is associated with three others (e.g., "apple" completes the triad formed by pine, crab, and sauce) (see Bowden & Jung-Beeman, 2003). Intermediate confidence ratings (see Figure 1) were collected every 15 seconds. She found that, for any given solution attempt, confidence increased from the initial to the final judgment. However, the confidence level at which participants gave their final solutions decreased over time: When problems were solved quickly, participants tended to respond with solutions that they were highly confident in. When problems took longer to solve, participants appeared to compromise on their confidence criterion, and were willing to provide solutions with less confidence. See Figure 2, Panel A.

In one condition, participants were also provided the option to say that they "don't know". This option allowed Ackerman (2014) to examine a less well-studied termination decision, namely the one in which people essentially "give up". Even when the option to give up was made legitimate, allowing participants to provide only those solutions in which they were highly confident, they nonetheless continued to provide solutions with low confidence after a lengthy solution attempt. See Figure 2, Panel B. Taken together, these findings suggest that people’s aspirational level of confidence decreases over time, which Ackerman referred to as the Diminishing Criterion Model.

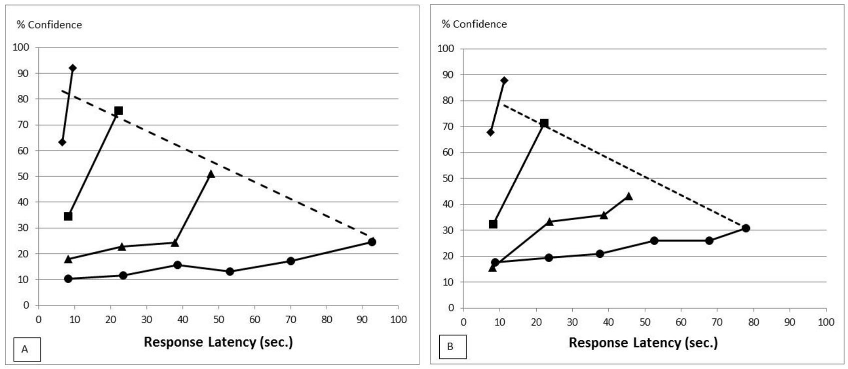

Figure 2. Intermediate and final confidence ratings provided along solving of compound remote associate problems. For this figure, the problems each participant solved were divided into four response latency quartiles. Each line represents the means of a quartile across participants. The dashed lines represent the regression lines for final confidence predicted by response latency. Panel A presents data without the option to answer by “I don’t know” and Panel B presents data with this option. The figures were adapted from Ackerman (2014), Figure 5b and Figure 6b, respectively.

In sum, collecting metacognitive judgments in reasoning tasks allows us to understand variables that determine control decisions to initiate analytic thinking (or not), to continue investing effort (or not), when to terminate effort, and how to convey the outcome (e.g., a concrete answer vs. a “don’t know” response, or the detail level of the explanation one can provide).

3. *Knowledge Activation*

Clearly, successful reasoning is facilitated by the retrieval and application of relevant background knowledge (Butler & Winne, 1995). This knowledge falls into several categories. First, there is knowledge about the specific concepts being reasoned about, like category relatedness in an inference task (e.g., “all canaries are birds”). Second, structured knowledge facilitates retrieval of relevant associations, such as analogies from different domains (e.g., Duncker's radiation problem in which participants must make the analogy for how treating a tumor is like attacking a fortress from several directions, see Holyoak, 1990). Third, one may access knowledge about the procedures needed to solving the problem (e.g., the set of steps required for solving a cubic equation). Finally, adequate proficiency is required for performing each step (e.g., calculating X^2 or sin(X)).

At a first glance, it seems that having a lot of knowledge associated with a reasoning task is an advantage, because additional knowledge allows more solution alternatives and strategies to be considered, which should increase the probability of solving (see Chi, Glaser, & Farr, 1988; Ericsson & J. Smith, 1991; Thibodeau & Boroditsky, 2012). However, in addition to retrieving relevant knowledge, one needs to be able to ignore or suppress *irrelevant* information (Passolunghi & Siegel, 2001). In particular, background knowledge may appear to be relevant, based on surface level cues, but can be quite misleading. Thus, it may not facilitate a solution, but actually hinder it (e.g., Storm & Hickman, 2015; Wiley, 1998). For example, in logical reasoning tasks, reasoners are often instructed to put aside their beliefs and reason only about the logical structure of the argument. Instead, however, reasoners often judge the validity of the conclusion according to whether or not they believe it to be true (see Thompson, Newstead, & Morley, 2011, for a review; Thompson & Ball, this volume).

Clearly, therefore, accurate monitoring of retrieved knowledge is required for effective reasoning (see Figure 1). As with the other forms of monitoring that we have discussed, the evidence shows that monitoring our knowledge is not always accurate. On the one hand, a robust finding is that people who are more knowledgeable in a domain are also better at assessing their knowledge than those who are less knowledgeable (Dunning et al., 2003; Kleitman & Moscrop, 2010). On the other hand, a recent study demonstrated that monitoring of reasoning may also be biased by the subjective feeling of having a lot of knowledge related to a task, even if it is not relevant. Ackerman and Beller (under review) asked participants to solve compound remote associates, as described previously, except that half of the problems were unsolvable (i.e., three words without a shared association). Participants quickly provided an initial Judgment of Solvability (2 sec.) about whether or not the triad was solvable. In addition, their procedure included also a final Judgment of Solvability, which was not included in the original Meta-Reasoning framework (Ackerman & Thompson, 2015). This judgment was collected when the respondents gave up the problem (“don’t know”). It reflects the assessed chance that the problem is solvable despite the participant’s failure to solve it (see Figure 1).

Ackerman and Beller (under review) examined accessibility as a heuristic cue for both Judgments of Solvability. Accessibility is defined as the amount, rather than the correctness or relevance, of information that comes to mind while performing a cognitive task. It was found to underlie Feeling of Knowing while answering knowledge questions (Koriat, 1995; Koriat & Levy-Sadot, 2001). Similarly, in the remote associates task, both Judgments of Solvability (initial and final) were led astray so to be higher for the high accessibility triads than for low accessibility ones, even though the accessible knowledge was not useful for solving the problems. Thus, having a lot of related knowledge may lead people to predict a high probability of success in the task, even when this knowledge does not predict actual success rates. These findings may generalize to the "take the best" heuristic discussed above, because it appears in both cases that monitoring processes are biased by the volume of available information.

Others have also observed that reasoning monitoring may be influenced by irrelevant information. Josephs, Silvera, and Giesler (1996) gave their participants either a large (200) or a small (25) number of anagrams as a practice set. Importantly, they emphasized that the size of the practice set was arbitrary and the participants could ask for more practice problems, as needed. The participants were free to practice as much as they wanted and to decide when they were ready to take the test. Thus, the participants were encouraged to monitor their skill level in solving anagrams, and take a control decision to stop practicing. When the anagrams were all of a similar level of difficulty, the participants were good at identifying when they were ready to take the test. However, when the problems were of mixed difficulty levels, the participants used the number of practice problems in the given practice package (200 or 25) as a cue that guided their decision when to take the solving test. When the practice set was large (200), the participants continued practicing longer than when it was small (25), despite the package size being random and unrelated to their actual solving skill. In sum, knowing when the information one has available is relevant or misleading is important to achieving good reasoning outcomes. To date, we have barely begun to understand how this monitoring is achieved.

4. Strategy selection

In addition to the types of online monitoring and control strategy described above, there is a rich educational literature on other aspects of metacognition that fall under the umbrella of Self-Regulated Learning (SRL). Strategy selection for learning and problem solving is a central topic in this literature (e.g., Edwards, Weinstein, Goetz, & Alexander, 2014; Schneider & Artelt, 2010). It has been consistently observed that posing questions like ‘‘how”, ‘‘why” and ‘‘in which circumstances” to students encourages reflection, promotes deliberate engagement in strategy choice, and yields improved performance (e.g., Mevarech, Terkieltaub, Vinberger, & Nevet, 2010; see Zimmerman, 2000, for a review).

Less work has been done to understand how reasoners select a strategy. Most research in this domain has focussed on the costs of carrying out each potential strategy, with the ultimate goal to choose the least demanding strategy that might work (e.g., Beilock & deCaro, 2007). However, we know very little about metacognitive monitoring and control processes involved in strategy search and selection (see Figure 1). An early exception to this general statement is a study conducted by Reder and Ritter (1992), who demonstrated that monitoring that is based on misleading information may then mislead strategy selection. They presented participants with arithmetic problems (e.g., 23 + 27), some of which were repeated several times. They then presented problems that shared surface, but not functional features with the previous problems (i.e., 23 X 27) and asked participants to rapidly decide whether they needed to calculate the answer or could remember the answer from their previous encounters. They found that familiarity was a misleading cue for this decision: numbers which appeared familiar from the previous trials misled participants into thinking that they could retrieve the answer without calculation.

Recent evidence suggests that the decision to adopt one strategy or another may be a substantial component of effortful, deliberate thinking. Empirical support for this idea comes from several studies which compared reasoning with and without time pressure (e.g., Bröder & Newell, 2008; Rieskamp & Hoffrage, 2008). For instance, Markovits, Brunet, Thompson, and Brisson (2013) used a conditional inference task, in which people are asked to make inferences about statements of the form “if *p*, then *q*”, and assessed whether reasoners evaluated inferences on the basis of the probability that it was true, or by using counter-examples. As an illustration, one might accept the following argument because it has a high probability of being true: “If an animal is a dog, then it has four legs; this animal is a dog, therefore it has four legs” or reject it on the basis that not every dog has four legs (i.e., there are counter-examples to the conclusion). When put under time pressure, reasoners relied on the probabilistic strategy; when given the opportunity to solve the problems in free time, they switched and used the counter-example strategy. In contrast, those who first solved the problems under free time used the counter example strategy even when put under time pressure. Thus, it is not merely a lack of capacity that drove reasoners to use the probabilistic strategy, but, instead, that time pressure disrupted their ability to choose the preferred strategy.

In our view, choosing the appropriate strategy is essentially a metacognitive process (see also Bröder & Newell, 2008). The metacognitive monitoring involved in strategy selection requires assessing relevant background knowledge and skills and predicting in advance which strategy would be most effective; the metacognitive control process is the choice of the strategy. As is the case for the other types of monitoring we have discussed, it seems reasonable to speculate that the assessment of strategy effectiveness is based on heuristic cues. It follows, therefore, that the quality of strategy selection will depend on the reliability of the cues that inform these monitoring processes, as is the case for the other processes we have discussed.

5. Cognitive ability

The positive relationship between measures of general cognitive ability and reasoning is clear and well established (Sonnleitner, Keller, Martin, & Brunner, 2013; Stanovich & West, 2000). A central factor underlying this association is working memory capacity (Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004). Working memory determines whether one has the capacity to solve a problem, it also affects people's choice of a solution strategy (Beilock & DeCaro, 2007). In contrast, we know little about the relationship between cognitive ability and the metacognitive processes involved in reasoning.

What we do know is that there is a personal confidence trait which is generally reliable (see Stankov, Kleitman, & Jackson, 2014, for a review). That is, averaged across tasks, a person's confidence judgments show high internal consistency; confidence judgments tend to be consistent across different cognitive tests and they are positively associated with the person's average performance. In addition, the tendency to be under- or overconfident is also consistent across tasks. Another measure of monitoring accuracy called resolution, the extent to which confidence judgments discriminate between correct and wrong responses, is also correlated with performance measures (Jackson & Kleitman, 2014). Particularly relevant for this section is the finding that these metacognitive measures at the individual level are positively associated with measures of general cognitive ability (Jackson & Kleitman, 2014; Kleitman & Moscrop, 2010), meaning that the confidence judgments of high ability reasoners show better resolution. Similarly, from learning studies, we know that overconfidence tends to get higher with lower performance (Dunning et al., 2003; Dunlosky & Rawson, 2012). This is also the case in reasoning (Stankov & Lee, 2014).

Recently, theorists (e.g., Fletcher & Carruthers, 2012; Stanovich, 2009), have suggested that an important component in reasoning performance is the ability to be reflective—that is, the disposition to monitor the adequacy of one's intermediate reactions before settling on a final response. This is in line with the conceptualization of metacognition as a deliberate reflective process mentioned above. Indeed, Thompson and Johnson (2014) found that high-capacity reasoners (relative to their low-capacity peers) showed more sensitivity to features of the problem (response conflict) that were signs of problem difficulty, adjusting their rethinking time and the probability of changing answers accordingly.

6. Conclusion

In this chapter, we have presented evidence to support the conclusion that metacognitive monitoring and control processes are central elements of every aspect of reasoning: initiating and terminating thinking, strategy selection, knowledge monitoring, and individual differences Also, despite the origins of metacognitive reasoning theory in a dual process framework, we have shown how a metacognitive analysis extends beyond those borders to apply in a wide range of theoretical views, including mental model theory, probabilistic reasoning approaches, and fast-and-frugal decision-making. In sum, an adequate understanding of performance on a broad spectrum of reasoning tasks requires a concomitant understanding of the metacognitive processes involved.

References

Ackerman, R. (2014). The Diminishing Criterion Model for metacognitive regulation of time investment. *Journal of Experimental Psychology: General, 143*(3), 1349-1368.

Ackerman, R., & Beller, Y. (under review). Shared and distinct cue utilization for metacognitive judgments during reasoning and memorization.

Ackerman, R., & Leiser, D. (2014). The effect of concrete supplements on metacognitive regulation during learning and open-book test taking. *British Journal of Educational Psychology, 84*(2), 329–348.

Ackerman, R. & Thompson, V. (2015). Meta-Reasoning: What can we learn from meta-memory. In A. Feeney & V. Thompson (Eds.), *Reasoning as Memory* (pp. 164-178). Hove, UK: Psychology Press.

Ackerman, R., & Zalmanov, H. (2012). The persistence of the fluency–confidence association in problem solving. *Psychonomic Bulletin & Review, 19*(6), 1187-1192.

Alter, A. L., Oppenheimer, D. M., Epley, N., & Eyre, R. N. (2007). Overcoming intuition: Metacognitive difficulty activates analytic reasoning. *Journal of Experimental Psychology: General, 136*(4), 569-576.

Beilock, S. L., & DeCaro, M. S. (2007). From poor performance to success under stress: working memory, strategy selection, and mathematical problem solving under pressure. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(6), 983-998.

Benjamin, A. S., Bjork, R. A., & Schwartz, B. L. (1998). The mismeasure of memory: When retrieval fluency is misleading as a metamnemonic index. *Journal of Experimental Psychology: General, 127*(1), 55-68.

Bjork, R. A., Dunlosky, J., & Kornell, N. (2013). Self-regulated learning: Beliefs, techniques, and illusions. *Annual review of psychology, 64*, 417-444.

Bowden, E. M., & Jung-Beeman, M. (2003). Normative data for 144 compound remote associate problems. *Behavior Research Methods, 35*(4), 634-639.

Bröder, A., & Newell, B. R. (2008). Challenging some common beliefs: Empirical work within the adaptive toolbox metaphor. *Judgment and Decision Making*, *3*(3), 205-214.

Butler, D. L., & Winne, P. H. (1995). Feedback and Self-Regulated Learning: A Theoretical Synthesis. *Review of Educational Research, 65*(3), 245-281. Retrieved from FTXT file BG

Chater, N., & Oaksford, M. (1999). The probability heuristics model of syllogistic reasoning. *Cognitive Psychology*, 38, 191–258.

Chi, M. T. H., Glaser, R., & Farr, MJ (1988). *The nature of expertise.* Hillsdale, NJ: Erlbaum .

Colom, R., Rebollo, I., Palacios, A., Juan-Espinosa, M., & Kyllonen, P. C. (2004). Working memory is (almost) perfectly predicted by g. *Intelligence*,*32*(3), 277-296.

Cummins, D. D., Lubart, T., Alksnis, O., & Rist, R. (1991). Conditional reasoning and causation. *Memory & Cognition*, *19*(3), 274-282.

De Neys, W. (2014). Conflict detection, dual processes, and logical intuitions: Some clarifications. *Thinking & Reasoning*, *20*(2), 169-187.

De Neys, W., & Bonnefon, J. F. (2013). The 'whys' and 'whens' of individual differences in thinking biases. *Trends in cognitive sciences*, *17*(4), 172-178.

De Neys, W, Cromheeke, S., & Osman, M. (2011). Biased but in doubt: Conflict and decision confidence. *PLoS ONE, e15954* doi:10.1371/journal.pone.0015954.

Dunlosky, J., & Rawson, K. A. (2012). Overconfidence produces underachievement: Inaccurate self evaluations undermine students' learning and retention. *Learning and Instruction, 22*(4), 271-280.

Dunning, D., Johnson, K., Ehrlinger, J., & Kruger, J. (2003). Why people fail to recognize their own incompetence. *Current Directions in Psychological Science, 12*, 83-87.

Edwards, A. J., Weinstein, C. E., Goetz, E. T., & Alexander, P. A. (2014). *Learning and study strategies: Issues in assessment, instruction, and evaluation*: Elsevier.

Ericsson, K. A., & Smith, J. (1991). *Toward a general theory of expertise: Prospects and limits*. Cambridge University Press.

Evans, J. S. B. T. (2006). The heuristic-analytic theory of reasoning: Extension and evaluation. *Psychonomic Bulletin & Review, 13*(3), 378-395.

Evans, J. S. B. T. (2007). On the resolution of conflict in dual process theories of reasoning. *Thinking & Reasoning, 13*(4), 321-339.

Evans, J. S. B. T., & Curtis-Holmes, J. (2005). Rapid responding increases belief bias: Evidence for the dual-process theory of reasoning. *Thinking & Reasoning, 11*(4), 382-389.

Evans, J. S. B. T., & Stanovich, K. E. (2013). Dual-process theories of higher cognition advancing the debate. *Perspectives on Psychological Science, 8*(3), 223-241.

Finucane, M. L., Alhakami, A., Slovic, P., & Johnson, S. M. (2000). The affect heuristic in judgments of risks and benefits. *Journal of Behavioral Decision Making*, 13, 1–17.

Fletcher, L., & Carruthers, P. (2012). Metacognition and reasoning. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 367*, 1366-1378.

Funke, J. (2010). Complex problem solving: a case for complex cognition? *Cognitive processing, 11*(2), 133-142.

Gigerenzer, G., Todd, P., & ABC Research Group (1999). *Simple heuristics that make us smart*. New York: Oxford University Press.

Gilovich, T., Griffin, D., & Kahneman, D. (2002). *Heuristics and biases: The psychology of intuitive judgment*. Cambridge University Press.

Hilbig, B. E. (2010). Reconsidering "evidence" for fast-and-frugal heuristics.*Psychonomic Bulletin & Review*, *17*(6), 923-930.

Holyoak, K. J. (1990). Problem solving. *Thinking: An invitation to cognitive science, 3*, 117-146.

Jackson, S. A., & Kleitman, S. (2014). Individual differences in decision-making and confidence: capturing decision tendencies in a fictitious medical test. *Metacognition and Learning, 9*(1), 25-49.

Johnson-Laird, P. N., & Byrne, R. M. (1991). *Deduction*. Lawrence Erlbaum Associates, Inc.

Johnson-Laird, P. N., & Byrne, R. M. (2002). Conditionals: a theory of meaning, pragmatics, and inference. *Psychological review*, *109*(4), 646.

Josephs, R. A., Silvera, D. H., & Giesler, R. B. (1996). The learning curve as a metacognitive tool. *Journal of experimental psychology. Learning, memory, and cognition, 22*(2), 510-524.

Kahneman, D. (2011). *Thinking, Fast and Slow*. New York: Farrar, Straus and Giroux.

Karpicke, J. D., & Roediger, H. L. (2008). The critical importance of retrieval for learning. *Science, 319*, 966-968.

Kleitman, S. & Mascrop, T. (2010). Self-Confidence and Academic Achievements in Primary-School Children: Their Relationships and Links to Parental Bonds, Intelligence, Age, and Gender (pp. 293–326). In A. Efklides and P. Misailidi (Ed). *Trends and Prospects in Metacognition Research*, US: Springer.

Koriat, A. (1995). Dissociating knowing and the feeling of knowing: Further evidence for the accessibility model. *Journal of Experimental Psychology: General; Journal of Experimental Psychology: General, 124*(3), 311-333.

Koriat, A. (1997). Monitoring one's own knowledge during study: A cue-utilization approach to judgments of learning. *Journal of Experimental Psychology: General, 126*, 349-370.

Koriat, A. (2012). The self-consistency model of subjective confidence. *Psychological review, 119*(1), 80-113.

Koriat, A., Bjork, R. A., Sheffer, L., & Bar, S. K. (2004). Predicting one's own forgetting: The role of experience-based and theory-based processes. *Journal of Experimental Psychology: General, 133*(4), 643-656.

Koriat, A., & Levy-Sadot, R. (2001). The combined contributions of the cue-familiarity and accessibility heuristics to feelings of knowing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*(1), 34-53.

Koriat, A., Sheffer, L., & Ma'ayan, H. (2002). Comparing objective and subjective learning curves: Judgments of learning exhibit increased underconfidence with practice. *Journal of Experimental Psychology-General, 131*(2), 147-162.

Kruglanski, A. W., & Gigerenzer, G. (2011). Intuitive and deliberate judgments are based on common principles. *Psychological review*, *118*(1), 97.

Markovits, H. (1986). Familiarity effects in conditional reasoning. *Journal of Educational Psychology*, *78*(6), 492.

Markovits, H., Brunet, M. L., Thompson, V., & Brisson, J. (2013). Direct evidence for a dual process model of deductive inference. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *39*(4), 1213.

Markovits, H., Thompson, V. A., & Brisson, J. (2015). Metacognition and abstract reasoning. *Memory & cognition*, *43*(4), 681-693.

Metcalfe, J. (1998). Cognitive optimism: Self-deception or memory-based processing heuristics? *Personality and Social Psychology Review, 2*(2), 100-110. Retrieved from FTXT - OSL

Metcalfe, J., & Finn, B. (2008). Evidence that judgments of learning are causally related to study choice. *Psychonomic Bulletin & Review, 15*(1), 174-179.

Metcalfe, J., & Finn, B. (2011). People's hypercorrection of high-confidence errors: Did they know it all along? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(2), 437-448.

Mevarech, Z. R., Terkieltaub, S., Vinberger, T., & Nevet, V. (2010). The effects of meta-cognitive instruction on third and sixth graders solving word problems. *ZDM, 42*(2), 195-203.

Meyer, A., Frederick, S., Burnham, T. C., Guevara Pinto, J. D., Boyer, T. W., Ball, L. J., ... & Schuldt, J. P. (2015). Disfluent fonts don't help people solve math problems. *Journal of Experimental Psychology: General*, *144*(2), e16.

Nelson, T. O., & Narens, L. (1990). Metamemory: A theoretical framework and new findings. In G. Bower (Ed.), *The Psychology of learning and motivation: Advances in research and theory* (Vol. 26, pp. 125-173). San Diego, CA: Academic Press.

Newell, B. R., & Bröder, A. (2008). Cognitive processes, models and metaphors in decision research. *Judgment and Decision Making*, *3*(3), 195-204.

Newell, B. R., & Shanks, D. R. (2003). Take the best or look at the rest? Factors influencing" one-reason" decision making. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*(1), 53.

Newell, B. R., Weston, N. J., & Shanks, D. R. (2003). Empirical tests of a fast-and-frugal heuristic: Not everyone "takes-the-best". *Organizational Behavior and Human Decision Processes*, *91*(1), 82-96.

Oaksford, M., & Chater, N. (2007). *Bayesian rationality: The probabilistic approach to human reasoning*. Oxford University Press.
Osman, M. (2004). An evaluation of dual-process theories of reasoning. *Psychonomic Bulletin & Review*, 11(6), 988–1010.
Passolunghi, M. C., & Siegel, L. S. (2001). Short-term memory, working memory, and inhibitory control in children with difficulties in arithmetic problem solving. *Journal of Experimental Child Psychology, 80*(1), 44-57.
Prowse Turner, J. A., & Thompson, V. A. (2009). The role of training, alternative models, and logical necessity in determining confidence in syllogistic reasoning. *Thinking & Reasoning*, 15, 69–100.
Quayle, J. D. & Ball, L. J. Working memory, metacognitive uncertainty, and belief bias in syllogistic reasoning. *Quarterly Journal of Experimental Psychology, 53A,* 1202-1223.
Rabinowitz, J. C., Ackerman, B. P., Craik, F. I. M., & Hinchley, J. L. (1982). Aging and metamemory: The roles of relatedness and imagery. *Journal of Gerontology, 37*(6), 688-695.
Reder, L. M., & Ritter, F. E. (1992). What determines initial feeling of knowing? Familiarity with question terms, not with the answer. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*(3), 435-451.
Rhodes, M. G., & Castel, A. D. (2008). Memory predictions are influenced by perceptual information: Evidence for metacognitive illusions. *Journal of Experimental Psychology: General, 137*(4), 615-625.
Rieskamp, J., & Hoffrage, U. (2008). Inferences under time pressure: How opportunity costs affect strategy selection. *Acta psychologica*, *127*(2), 258-276.
Rozenblit, L., & Keil, F. (2002). The misunderstood limits of folk science: An illusion of explanatory depth. *Cognitive Science, 26*, 521-562. Retrieved from FTXT and materials - BG
Schneider, W., & Artelt, C. (2010). Metacognition and mathematics education. *ZDM, 42*(2), 149-161.
Shynkaruk, J. M., & Thompson, V. A. (2006). Confidence and accuracy in deductive reasoning. *Memory & Cognition*, 34, 619–632.
Sonnleitner, P., Keller, U., Martin, R., & Brunner, M. (2013). Students' complex problem-solving abilities: Their structure and relations to reasoning ability and educational success. *Intelligence, 41*(5), 289-305.
Stankov, L., Kleitman, S., & Jackson, S. A. (2014). Measures of the Trait of Confidence. In G. J. Boyle, D. H. Saklofske, & G. Matthews (Eds.), *Measures of personality and social psychological constructs* (pp. 158-189): Academic Press.
Stankov, L., & Lee, J. (2014). Overconfidence across world regions. *Journal of Cross-Cultural Psychology, 45*(5), 821-837.
Stanovich, K. E. (1999). *Who is rational?: Studies of individual differences in reasoning*. Psychology Press.
Stanovich, K. E. (2009). Distinguishing the reflective, algorithmic, and autonomous minds: Is it time for a tri-process theory? In J. Evans & K. Frankish (Eds.), *In two minds: Dual processes and beyond* (pp. 55-88). Oxford, UK: Oxford University Press.
Stanovich, K. E., & West, R. F. (2000). Individual difference in reasoning: Implication for the rationality debate. *Behavioural and Brain Science*, *23*, 645-665.
Storm, B. C., & Hickman, M. L. (2015). Mental fixation and metacognitive predictions of insight in creative problem solving. *The Quarterly Journal of Experimental Psychology, 68*(4), 802-813.
Sungkhasettee, V. W., Friedman, M. C., & Castel, A. D. (2011). Memory and metamemory for inverted words: Illusions of competency and desirable difficulties. *Psychonomic Bulletin & Review, 18*, 973-978.
Thibodeau, P. H., & Boroditsky, L. (2013). Natural language metaphors covertly influence reasoning. *PLoS One, 8*(1), e52961.
Thiede, K. W., Anderson, M. C. M., & Therriault, D. (2003). Accuracy of metacognitive monitoring affects learning of texts. *Journal of Educational Psychology, 95*(1), 66-73.
Thompson, V. A. (2000). The task-specific nature of domain-general reasoning. *Cognition*, 76, 209–268.
Thompson, V. A. (2009). Dual-process theories: A metacognitive perspective. In J. Evans & K. Frankish (Eds.), *In two minds: Dual processes and beyond* (pp. 171-195). Oxford, UK: Oxford University Press.
Thompson, V. A., Evans, J. S. B., & Campbell, J. I. (2013). Matching bias on the selection task: It's fast and feels good. *Thinking & Reasoning*, *19*(3-4).
Thompson, V. A., & Johnson, S. C. (2014). Conflict, metacognition, and analytic thinking. *Thinking & Reasoning*, *20*(2), 215-244.
Thompson, V. A., Newstead, S. E., & Morley, N. J. (2010). 15 Methodological and theoretical issues in belief bias. *The Science of Reason: A Festschrift for Jonathan St BT Evans*, 309.
Thompson, V. A., Prowse Turner, J., & Pennycook, G. (2011). Intuition, reason, and metacognition. *Cognitive Psychology, 63*(3), 107-140.

Thompson, V. A., Turner, J. A. P., Pennycook, G., Ball, L. J., Brack, H., Ophir, Y., & Ackerman, R. (2013). The role of answer fluency and perceptual fluency as metacognitive cues for initiating analytic thinking. *Cognition*,*128*(2), 237-251.

Topolinski, S. (2014). Intuition: Introducing affect into cognition. In A. Feeney & V. Thompson (Eds.), *Reasoning as memory* (pp. 146-163). Hove, UK: Psychology Press.

Topolinski, S., & Reber, R. (2010). Immediate truth-Temporal contiguity between a cognitive problem and its solution determines experienced veracity of the solution. *Cognition, 114*(1), 117-122.

Undorf, M., & Erdfelder, E. (2015). The relatedness effect on judgments of learning: A closer look at the contribution of processing fluency. *Memory & cognition, 43*(4), 647-658.

Vernon, D., & Usher, M. (2003). Dynamics of metacognitive judgments: Pre-and postretrieval mechanisms. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(3), 339-346.

Weber, N., & Brewer, N. (2006). Positive versus negative face recognition decisions: Confidence, accuracy, and response latency. *Applied Cognitive Psychology, 20*(1), 17-31.

Wiley, J. (1998). Expertise as mental set: The effects of domain knowledge in creative problem solving. *Memory & cognition, 26*(4), 716-730.

Zimmerman, B. J. (2000). Self-efficacy: An essential motive to learn. *Contemporary educational psychology, 25*(1), 82-91.