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Meta-Reasoning: What Can We Learn from Meta-Memory?

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Meta-Reasoning: What Can We Learn from Meta-Memory?

The past few decades have witnessed a surge of research in the area of metacognition in general, and meta-memory in particular. The foundational principles for this work were articulated in the framework developed by Nelson and Narens (1990). Although there have been substantial developments since then, the basic principles articulated there remain widely accepted (see Bjork, Dunlosky, & Kornell, 2013). These differentiate object-level from meta-level cognition: meta-level processes monitor and regulate ongoing object-level processes. To date, the bulk of the metacognitive literature is focused on the processes associated with learning, particularly, memorizing word lists. Here, object-level processes involve the transfer of information from an external source to the learner's memory system via one or more learning strategies (e.g., rehearsal, imagery, elaboration, etc.). The meta-level regulates these processes by setting goals, deciding among appropriate strategies, monitoring their progress and terminating an activity (Bjork et al., 2013).

Although these basic principles are clearly relevant for regulating the performance of many other cognitive tasks, relatively little is known about the meta-level processes involved in them. The present chapter is focused on meta-level processes involved in reasoning, including tasks such as decision making, logical reasoning, and problem solving. In some respects, there are strong analogies that can be made between meta-memory and meta-reasoning. For example, some reasoning tasks may be solved by retrieving an answer from memory. However, others cannot be solved in that way, and instead rely on deliberate, working-memory demanding processes that evolve over time (see Beilock & DeCaro, 2007). Even when a solution can be retrieved from memory, higher-order cognitive processes may be recruited to evaluate the adequacy of the answer and consider alternatives. Nevertheless, the meta-level in this context will involve processes that are similar to those that regulate learning, such as setting goals, deciding among strategies, monitoring progress and terminating an activity.

We first provide an overview of object-level processes in reasoning and then highlight well-established principles of meta-memory, with a focus on those that we think most appropriate for drawing analogies to reasoning. Our second goal is to consider ways in which the meta-level of reasoning may necessitate qualitatively different processes than those postulated to monitor and regulate memory. Finally, as the literature in meta-reasoning is in its infancy, one of our primary goals is to suggest productive avenues for further research, specifically with regards to meta-level processes unique to reasoning.

a. Object-Level Processes in Reasoning

Our analysis of object-level processes in reasoning derives from a Dual Processes perspective, which suggests that high-level cognition is accomplished by two qualitatively different types of processes (Evans & Stanovich, 2013). Type 1 processes are autonomous processes that are executed in the presence of their triggering conditions. These can produce instant judgments based on categorization, stereotypes, affect, linguistic processes, and memory retrievals (see Kahneman, 2003; Stanovich, 2004 for detailed analyses). Type 2 processes are differentiated from Type 1 processes by the fact that they require effortful thinking (Evans & Stanovich, 2013). These processes include inhibiting the prepotent Type 1 response, considering alternative responses, hypothetical thinking, searching memory for confirmatory or disconfirmatory evidence, applying rules of probability and logic, etc. We should note, that there is no sharp distinction between the domains that are served by each type of process. In particular, there are processes, like memory retrievals and categorization, that can both be accomplished by instant Type 1 and by deliberate Type 2 processing.

The key assumption from a Dual Process perspective is that Type 1 processes can occur autonomously, and suggest an immediate answer to reasoning challenges, as per the two examples below. The reasoning and decision-making literature is replete with dozens of such tasks, which are designed to promote an intuitive, but erroneous, initial answer (see Kahneman, 2011; Lehrer, 2009 for descriptions of real-world decisions that are similarly misleading). These initial answers can be overridden by Type 2 processes.

Example 1 (Frederick, 2005):
If it takes 5 machines 5 minutes to make 5 widgets, how long will it take 100 machines to make 100 widgets? ____ minutes
(100 is the immediate answer, while 5 is the correct one)

Example 2 (Wiley, 1998)**:**
Please generate a word, which when combined with each of the three following words would result in a common compound word or phrase: PLATE, BROKEN, SHOT
('home' comes immediately to mind, but fits only the first two words; 'glass' is correct)

In other cases, when no instant solution comes to mind, the problem can only be solved by recourse to explicit, working memory demanding (Type 2) processes, as per the examples below. For solving such challenging tasks, deliberate processing is required to represent the problem information, and/or for applying strategies such as means end analysis, hypothetical thinking, rules of logic and probability, and others (see Wang & Chiew, 2010).

Example 3:
Some of the Artists are not Beekeepers.
None of the Carpenters are Beekeepers.
Therefore, does it follows that none of the Carpenters are Artists?
("No" is correct)

Example 4 (Bowden & Jung-Beeman, 2003):
Generate a word, which when combined with each of the three following words would result in a common compound word or phrase: PEA, SHELL, CHEST
('nut' is the correct answer provided after 30 sec. only by 23% of the sample)

The role of meta-reasoning processes in this framework is to determine the circumstances under which the initial Type 1 process suffices and when the more effortful, Type 2 processes should be engaged (De Neys, 2012; Thompson, 2009). Meta-reasoning processes are also engaged during Type 2 processes for estimating the probability of success, judging progress towards a solution, and for allocating working memory resources, selecting among potential solving strategies, and deciding when the process should be terminated (Ackerman, in press; Payne & Duggan, 2011). We now introduce the meta-memory processes that may form a useful basis for theorizing about meta-reasoning processes.

b. Meta-memory judgments

Metacognitive monitoring of memory begins when the “to-be-remembered” item is encountered and continues during encoding and retrieval of the item (Nelson & Narens, 1990). Monitoring processes assess the outcome of the object level process, estimate the probability of successful recall, and regulate the amount and type of effort allocated to achieve one’s goals. Table 1 summarizes the monitoring processes that we believe most likely to provide useful analogies to meta-reasoning. The table also includes the meta-reasoning judgment we see as being closest in nature to each meta-memory judgment. We begin by providing a brief introduction to each meta-memory judgment and the activities it is hypothesized to control.

All the monitoring judgments that we describe are thought to be based on heuristic cues (Koriat, 1997; see Dunlosky & Tauber, 2014 for a review). On this view, people do not have direct access to their underlying cognitive processes, and instead, base their judgments on the cues that are available to them. One such cue is fluency (the ease or speed with which a cognitive task is completed), which is thought to underlie most meta-memory judgments. For example, easy or efficient processing of an item gives rise to the attribution that the item has been previously experienced, even when it has not (Jacoby, Kelley, & Dywan, 1989; Whittlesea, Jacoby, & Girard, 1990). The potentially misleading nature of the heuristic cues highlights the fact that meta-level judgments are independent from object-level processes, i.e., the cognitive processes themselves. Consequently, the predictive accuracy of these judgments depends greatly on the diagnosticity of the cues that underlie them.

Table 1 Parallels between meta-memory and meta-reasoning judgments

Meta-memory judgment			**Meta-reasoning judgment**
Name	**Object**	**Reference Time**	
Ease of Learning (EOL)	A particular study item or a complex study unit	Future	Judgment of Solvability (JOS)
Judgment of Learning (JOL)	A particular study item (e.g., a word)	Future	Judgments of ongoing reasoning processes
Judgment of Comprehension, comprehension rating or metacomprehension judgment	A complex study unit (e.g., a text)	Present	
Prediction of Performance	A complex study unit	Future	
Feeling of Knowing (FOK)	A particular test question	Future	
Feeling of Familiarity (FOF)	A particular memory retrieval	Present	Feeling of Rightness (FOR)
Confidence	A particular test answer	Present	Final Confidence Judgment (FCJ)

- **Ease of Learning (EOL) judgment –** EOLs are judgments of how easy or difficult something will be to learn, and are usually made after a brief exposure to the to-be-remembered item and before deliberate learning is undertaken. EOLs are thought to control the choice of processing strategy (Nelson & Narens, 1990) as well as the amount of effort invested in the task. For example, participants will allocate more study time to those items that they deem to be difficult (e.g., Son & Metcalfe, 2000). Interestingly, however, this effect reverses under time pressure, both for word pairs and complex text (Son & Metcalfe, 2000; Thiede & Dunlosky, 1999). Thus, when the time is limited, people skip the items they judge to be time consuming and strategically invest effort in easier ones.

Studies have shown EOLs, like other monitoring judgments, have low to medium predictive value for test performance (e.g., Karpicke, 2009). Koriat (1997) suggested that EOLs are based on participants' a-priori beliefs about how easy or challenging items of this type are to learn (see also Dunlosky & Tauber, 2014). Thus, the predictive value of EOLs will vary as a function of how well calibrated these a priori beliefs are with actual difficulty.

In the next section, we consider Judgments of Solvability (JOS; Thompson, 2009) as a possible analogue to EOLs in reasoning.

- **Judgment of Learning (JOL) –** JOLs concern the likelihood of remembering a particular item at a later recall attempt and are hypothesized to control the allocation of study time during learning. One model of how this is achieved is the discrepancy reduction model (Nelson & Narens, 1990), which suggests that people set a target that reflects their current motivation to succeed. They monitor their progress, studying each item until their knowledge is judged satisfactory (see Figure 1 in Ackerman & Goldsmith, 2011 for illustration). The control function of JOLs was revealed by the finding that, when JOLs were experimentally manipulated to deviate from actual degree of learning, it was the JOLs, rather than degree of learning, that predicted later study time (Metcalfe & Finn, 2008). Below, we suggest analogous mechanisms by which reasoners may regulate the effort they invest in problem-solving.

JOLs, like other metacognitive judgments, are thought to be based on heuristic cues (Koriat, 1997). Koriat, Ma'ayan, and Nussinson (2006) suggested that people use a memorizing effort heuristic, in which longer learning times (i.e., lower fluency) indicate a lower probability that it will later be recalled. In most cases, this heuristic is reliable, as items that take longer to learn are, indeed, harder to recall. Other cues are less reliable, for example, when JOLs are based on surface properties of the “to-be-learned items”. Rhodes and Castel (2008) had college students memorize words, half of which were printed in large font. JOLs were significantly higher for words printed in large than smaller font, but recall did not differ as a function of font size. Conversely, there are variables that have large effects on performance to which JOLs are less sensitive: Rehearsal improves recall and long delays between learning and test cause substantial forgetting, yet JOLs are not very sensitive to either (Koriat, 1997). Thus, the accuracy of JOLs, like other metacognitive judgments, depends on the validity of the utilized cues. The analogy to meta-reasoning suggests that the accuracy of judgments that accompany reasoning also depends on the reliability of the underlying heuristic cues.

- **Judgment of comprehension, comprehension rating, metacomprehension judgment, and predictions of performance –** Arguably, memorizing words provides few parallels to reasoning, given the discrepancy in the amount of time and effort required. However, metacognitive processes have also been studied in the context of learning from texts, which involves more complex object-level and meta-level processes. The object-level involves multi-level processing of word meaning and the integrative understanding of high-order ideas (Kintsch, 1998). The meta-level is correspondingly multidimensional and involves monitoring of memory for details and of higher-order comprehension (Ackerman & Goldsmith, 2011; Thiede, Wiley, & Griffin, 2011), and which can focus either on the current level of comprehension (Ackerman & Leiser, in press; Zaromb, Karpicke, & Roediger, 2010) or on predicting future test performance (e.g., Ackerman & Goldsmith, 2011; Maki, 1998). As was the case for JOLs, these judgments predict the allocation of study time (Thiede, Anderson, & Therriault, 2003).

The discrepancy reduction model described above (Nelson & Narens, 1990) has been adapted to these more complex tasks. Ackerman and Goldsmith (2011) had undergraduate students study texts that took about 9-10 minutes to learn. In one condition, participants stopped every three minutes, provided a prediction of performance based on their knowledge, and decided explicitly whether to continue or to take the test. The pattern of intermediate ratings followed a power law, consistent with the classic learning curve (Ebbinghaus, 1885/1964): Judgments started low, increased quickly and then levelled off, presumably at participants' stopping criterion. Below, we outline parallels between this regulation of effort and that occurring during reasoning (see section regarding ongoing judgments).

Unlike JOLs, judgments of comprehension have been found to have little predictive validity for performance (see Dunlosky & Lipko, 2007). One reason might be that it is difficult to judge the state of one's learning when there is uncertainty about the information that will be solicited at test. Another is that monitoring of comprehension has been found to rely on misleading surface-based cues. For example, the presence of illustrations can increase the *perceived* comprehensibility of the text (Chandler & Sweller, 1991; Serra & Dunlosky, 2010) and mislead the regulatory processes like those that underlie allocation of study time (Ackerman & Leiser, in press).

- **Feeling of Knowing (FOK)**–While the preceding judgements are used to monitor learning, FOK is associated with testing. The FOK is typically a judgment about the probability of recognizing the answer to a question (e.g., “In which city is the Uffizi Gallery located?”, Costermans, Lories, & Ansay, 1992) on a subsequent multiple-choice test. In cases where the answer to the question is currently unrecallable, FOKs have been shown to control the amount of effort participants invest in the item. For example, Reder and Ritter (1992) presented participants with a long list of arithmetic problems (e.g., 23 * 34). Some of the problems were presented several times, so that participants could retrieve their solution quickly instead of engaging in effortful calculations. Immediately after presentation, the participants had to quickly decide whether they could retrieve the solution from memory or would have to calculate it. Participants who had previously encountered problems with similar components (i.e., 23 + 34), tended to mistakenly indicate that they could retrieve the answer from memory. Thus, familiar components misled the participants to expect quick retrieval even for novel problems. Below, we propose that a judgment, called Feeling of Rightness, exerts a similar monitoring and regulatory function in reasoning.

Two heuristic cues are known to underlie FOKs. The first cue is the familiarity of the question terms. The above described study by Reder and Ritter (1992) is a case in point (see also Costermans et al., 1992). The second cue is accessibility, which reflects the number of associations that come to mind during a retrieval attempt, regardless of whether this information contributes to retrieving the correct answer (Koriat, 1993). For example, Koriat and Levy-Sadot (2001) composed general knowledge questions that differed in the familiarity of the terms (e.g., the ballets “Swan lake” vs. “The Legend of Joseph”) and in accessibility, which was operationalized as the amount of names people can provide for a category (e.g., people tend to know more composers than choreographers). These cues contributed additively to FOKs, such that FOKs were higher for the more familiar objects, but this effect was more pronounced for the highly accessible items.

- **Feeling of Familiarity (FOF)**– Jacoby and his colleagues (Jacoby et al., 1989) referred to the FOF as the *sine qua non* of remembering, without which a retrieval experience would not be labelled as a memory and have a sense of “pastness”. At its heart is the attributional nature of the experience, which was postulated to arise from experiences associated with retrieval, such as the ease or fluency with which the recalled item comes to mind (Jacoby et al., 1989; Whittlesea et al., 1990). For example, Fazendeiro, Winkielman, Luo, and Lorah (2005) had participants make “old” or “new” judgments of studied words (e.g., table), unstudied words that were semantically associated with studied words (e.g., chair), and unstudied and unrelated words. They found that the associated words were judged as “old” more often than the unstudied and unrelated words. The authors suggested that increased processing fluency of the associated words relative to the unstudied and unrelated words underlay this finding. Below, we draw parallels between the FOF and the Feeling of Rightness judgment in regarding reasoning tasks.

- **Confidence**–Confidence is a retrospective judgment that refers to the assessed probability that a question has been answered correctly. Confidence is often conceived of as a static, post-answer judgment (Nelson & Narens, 1990). However, Koriat and Goldsmith (1996) suggested that monitoring confidence is part of a cyclical process that occurs prior to as well as after giving an answer. Specifically, if an answer does not meet a threshold of confidence, it can be withheld in favour of either a “don’t know” response, or be given additional processing that may reformulate the answer. For example, if one is asked about the year of an event and one thinks that it was in 1995, but is not sure about it, a possible answer would be “I don’t know” or that “it was sometimes in the 90’s” (Ackerman & Goldsmith, 2008). Below, we consider a similar process to be involved in assessing the quality of intermediate and final outcomes in reasoning.

As with other metacognitive judgments described above, confidence varies with the fluency of production. Fluency of providing an answer can be a reliable cue when the questions are not misleading (Ackerman & Koriat, 2011). However, because judgments based on fluency are inferential, this cue may be also misleading. Below, we propose that similar mechanisms underlie confidence in reasoning.

c. Meta-Reasoning

In this section, we offer a framework for the metacognitive monitoring and regulation of reasoning, which is extrapolated from our discussion of meta-memory. At the object-level, learning and question answering share with reasoning tasks processes such as understanding meaning of words and syntax, identifying key information, retrieving relevant knowledge, and activating mental operations to achieve task goals (Kintsch, 1998; Wang & Chiew, 2010). At the meta-level, we consider several judgments hypothesized to take place during reasoning, and, as was the case with meta-memory judgments, we consider the associated regulatory processes as well as the heuristic basis for each judgment. Where available, we provide concrete evidence; but, because this research is still in the early stages, much of our discussion is speculative and is intended as a framework for future research.

- **Judgment of Solvability (JOS)** – When asked to memorize words, there is usually little doubt that any given single item can be learned. In contrast, in many reasoning tasks, it is possible that the task may not be solvable at all or that the participant lacks the requisite knowledge or capacity to solve it. In keeping with the principle of cognitive miserliness, people should be reluctant to invest time and effort in a task that has a low probability of success (e.g., De Neys, Rossi, & Houdé, 2013; see Stanovich, 2009 for a review). Thus, the very first decision that should take place is whether to attempt a solution at all. It may well be the case that the amount of effort thought to be required will be greater than the perceived benefits of solving the problem (Kruglanski et al., 2012). Thus, as was the case with ease of learning judgments (EOL), problems that are accompanied by low JOS are expected to lead to "giving up" when motivation is low or when under time pressure, and to result in a high investment when motivation is high.

What might be the basis of JOS's? That is, how might one judge, without having solved the problem, how difficult it will be to solve? As was the case with EOLs, we would expect that JOSs will be based on beliefs about the task at hand, about one's experience with solving such tasks, and on whatever surface-level cues are available from the problem that might signal difficulty. For example, metacognitive beliefs about reasoning ability can be measured using questionnaires such as the Rational Experiential Inventory (REI, Pacini & Epstein, 1999), which measures self-reported tendency to rely on analytic approaches to solving problems or to rely on past experiences and intuitions. Prowse Turner and Thompson (2009) demonstrated that rationality scores from the REI were positively correlated with confidence in solving complex logic problems; by extension, these types of metacognitive beliefs might also inform JOSs.

To the extent that JOSs are based on cues available from the problem, like EOLs, they should reflect some consensus amongst reasoners (Price & Murray, 2012). That is, one might expect consensus amongst participants regarding which items would be more difficult to solve. One such cue might be the difficulty of forming a representation or model of the problem (Johnson-Laird & Byrne, 1991). Consider the following two sets of premises:

1. All of the Artists are Bakers All of the Bakers are Carpenters	2. All of the Bakers are Artists All of the Bakers are Chemists

The first set of premises allows an easy integration of the problem information, whereas the second requires considerable re-working to align the common terms. On a reasoning task, reasoners are more confident with answers made from the first premises than the second (Stupple, Ball, & Ellis, 2013); it also seems reasonable to expect that similar differences would be observed in their JOSs.

Another cue that might be utilized is an apprehension of coherence amongst the problem elements. Topolinski (this volume) provides an overview of JOSs in the Remote Associate Test (Example 4). Specifically, he reviewed several studies demonstrating that people can distinguish between triads of words that are coherent (i.e., solvable) from those that are not. Importantly, these JOSs are produced in less time than it would take to produce the solution. Topolinski (this volume) argues that coherent items are processed more fluently than non-coherent ones and this gives rise to a positive, affective response allowing participants to make very fast JOSs. As is the case for inferential meta-memory judgements, however, such heuristic cues can be misleading (Alter & Oppenheimer, 2009). In particular, making some triads disfluent (by manipulating the contrast of the print) and inducing negative affect (by including negatively valenced words), lowered the probability that items were judged coherent.

In the absence of such cues, however, it seems unlikely that people will be able to judge the solvability of a problem. Using unsolvable water-jar problems, Payne and Duggan (2011) found that participants can only determine that a problem is insoluble after a lengthy attempt to solve it, if at all. Nevertheless, the ability to calibrate JOSs may increase with experience, at least with simpler tasks. Using anagrams (scrambled words), Novick and Sherman (2003) elicited solvability judgments under short deadlines (<1sec.). Accuracy increased with the amount of time allowed for the judgment. It also increased with experience, which probably allowed the extraction of reliable cues not apparent to novices.

- **Feeling of Rightness (FOR)** – Thompson and colleagues (Thompson, 2009; Thompson, Prowse Turner, & Pennycook, 2011; Thompson et al., 2013) have proposed FOR as a monitoring mechanism for those cases in which Type 1 processes have produced a quick intuitive answer to a reasoning problem (Examples 1 and 2 above). FOR is proposed to determine the extent to which the initial answer is subsequently analyzed by more deliberate, Type 2 processes. To test this hypothesis, Thompson and colleagues (Thompson et al., 2011, 2013) developed a two-response paradigm in which participants are asked to provide an initial, intuitive answer to a problem and then rate their FOR about that answer. They are then given free time to rethink their response. They found, in a variety of reasoning tasks, that low FORs are associated with more time spent rethinking the initial answer and a higher probability of changing the initial answers than high FORs. Thus, FOR judgments appear to play a monitoring role regarding Type 1 outputs and a regulatory role in initiating analytic thinking.

The monitoring and regulation processes associated with FOR judgments combine the roles of several of the meta-memory processes described above. Because Type 1 processes are fast and autonomous, these answers pop into mind in a fashion similar to quick memory retrieval (Topolinski & Reber, 2010). Thus, feeling of familiarity (FOF) provides one good analogues for thinking about FOR. That is, both the FOR and FOF are attributions one makes about the "rightness" of an answer that has just come to mind. In the case of the FOR, this subjective experience of "rightness" also plays a regulatory function over the subsequent investment of effort in the task, similar to that played by the Feeling of Knowing (FOK) and Judgments of Learning (JOL). The analogy to JOL suggests that the discrepancy reduction model described above may be relevant. On this hypothesis, reasoners would set a target for the level of confidence they want to have in their final answers, monitor their reasoning processes, and stop when they judge their level of confidence to suffice (see Ackerman, in press; Evans, 2006).

What mediates the strength of FORs? Like the meta-memory judgments we have discussed, the FOR is assumed to involve an attribution based on the experience of producing the initial answer. Thompson and colleagues (Thompson et al., 2011, 2013) examined fluency of producing the first answer that comes to mind as one of the cues underlying FOR. Across a wide range of tasks, they observed that a) answer fluency, operationalized as the speed with which an initial answer is produced, predicts FOR judgments, such that fluent responding is associated with strong FORs, b) factors that increase or decrease answer fluency, such as the ready availability of a heuristic strategy or whether a problem cues competing answers, decrease FORs. Thus, the fluency of answering a reasoning problem may form a basis of an attribution of rightness.

Although the FOR appears similar in many respects to the meta-memory judgments described above, there is an important way in which they differ. There, we described how meta-memory judgments are sensitive to perceptual fluency, such as making text easier to read by presenting it in large print (e.g., Jacoby et al., 1989; Kleider & Goldinger, 2004; Kornell, Rhodes, Castel, & Tauber, 2011; Rhodes & Castel, 2008). The initial reports appeared to indicate perceptual fluency also played a role in reasoning, such that making problems difficult to read increased participants' solution rates, presumably by creating a sense of metacognitive unease (e.g., Alter, Oppenheimer, Epley, & Eyre, 2007). The generalizability of these findings, however, turns out to be limited, as perceptual fluency was not found to affect either FORs or retrospective confidence judgments for variety of reasoning tasks (Thompson et al., 2013). We speculate that perceptual fluency may be too subtle a cue to manifest itself in FOR judgments, particularly in the presence of a very salient alternative, such as answer fluency.

What other cues may underlie FOR? As mentioned in our discussion of FOKs, Reder and Ritter (1992) found that the familiarity of the terms included in the question was related to FOKs. Similarly, Shynkaruk and Thompson (2006) found that reasoners expressed lower levels of confidence in conclusions about unfamiliar concepts than familiar ones, suggesting that familiarity may play a similar role in FOR judgments. FOKs are also known to vary with the accessibility of associations that come to mind during a retrieval attempt (Koriat, 1993). A similar process can be posited for reasoning, in that FORs and confidence judgments may increase with the amount of available information that is consistent with a conclusion; in the case of FOR, this might happen by automatic priming, whereas for final confidence judgments, it may be as a result of a deliberate memory search.

- **Ongoing judgments: Warmth ratings, intermediate confidence ratings, and dynamic Prediction of Knowing (dPOK)**–In contrast to the situations described above, for many reasoning tasks, an answer does not easily come to mind (Examples 3 and 4 above). Instead, deliberate processing is required to generate even an initial solution. Not much is known about metacognitive processes that might be involved; the few relevant findings are discussed below.

Metcalfe and Wiebe (1987) solicited intermediate metacognitive judgments while solving insight problems (e.g., water lilies problem, Frederick, 2005) and non-insight problems (e.g., Tower of Hanoi). Participants were asked to indicate every 15 seconds how "warm" they were getting on a cold-hot Likert scale (1-7). Warmth ratings increased over the solution interval; however, the increase was incremental for the non-insight problems and sudden for the insight problems.

Ackerman (in press) provided a more detailed look at the regulatory function of intermediate confidence ratings while solving math and word problems, similar to Examples 1 and 4 above. The confidence ratings were elicited by a 0-100% scale ranging from "I still have no idea" and "I've got it". As Metcalfe and Wiebe (1987) observed, confidence increased over the problem-solving interval. In addition, Ackerman observed that the very first confidence judgments, made about 5-10 seconds after the presentation of the problem, had strong predictive power: High levels of initial confidence were associated with less additional time spent solving the problem, similar to the relationship observed between FOR and analytic thinking (see Thompson et al., 2011, 2013).

Finally, Vernon and Usher (2003) collected ongoing dynamic Predictions of Knowing (dPOK) every four seconds until an allotted problem solving time of twelve seconds had elapsed. In one study, they primed the words for some of their Remote Associate Task items (Example 4 above), generating a familiar (or fluent) set of problems, while the others were unfamiliar. The familiar items showed higher initial dPOK than unfamiliar items, but both increased over time. The observed pattern resembled a power function, similar to the intermediate predictions of performance collected by Ackerman and Goldsmith (2011) during text learning.

As with text comprehension, monitoring of problem solving may be misled by the provision of irrelevant cues. For example, Ackerman, Leiser, and Shpigelman (2013) presented college students with difficult-to-solve problems. Immediately after attempting each problem, participants read an explanation for how to solve the problem, and were then asked to solve a near-transfer problem (Sasson & Dori, 2012) to test their understanding of the explanation. For some of the explanations, the text was accompanied by a non-informative illustration of an object mentioned in the explanation, while the other included just the text. Judgments of comprehension were higher for the illustrated explanations, while performance on the transfer problems was lower. Thus, the vulnerability of metacognitive monitoring to surface level cues extends to reasoning and problem-solving domains.

- **Final Judgments of Confidence (FJC) –** Thompson and colleagues coined this phrase to differentiate this judgment from the intermediate confidence judgments just described (Thompson et al., 2011). FJC refers to confidence in the final answer, after the reasoning or problem-solving is complete. As with answering knowledge questions, confidence is conceived as a post-answer judgment. However, as was the case with meta-memory judgments, intermediate levels of confidence could regulate the decision to provide an answer or withhold it. For example, performance on the Remote Associations Task (Example 4) can be improved by providing reasoners a "don't know" option (Ackerman, in press), similar to the effect observed for answering general knowledge questions (Koriat & Goldsmith, 1996). However, on problems that produce an initial misleading answer (Example 1), participants rarely used the "don't know" option, despite a very low success rates (about 35%). A potential reason may be that for these problems, Type 1 processes produce an answer candidate that comes to mind accompanied by high FOR, so that reasoners are not aware of having made an error (Ackerman & Zalmanov, 2012).

Not much is known about the processes that give rise to FJCs in reasoning tasks. From the existing research, it is apparent that reasoners are often overconfident in their answers and that their answers are poorly calibrated with accuracy (Ackerman & Zalmanov, 2012; Prowse Turner & Thompson, 2009; Shynkaruk & Thompson, 2006). One reason for the poor relationship between confidence and accuracy could be that participants rely on non-diagnostic cues to confidence. For example, as was the case for answering knowledge questions (Kelley & Lindsay, 1993), it appears that there is a negative relationship between solution time and FJC: Ackerman and Zalmanov (2012) found that participants were more confident in solutions that were produced quickly than solutions that were produced slowly. Notably, this negative time-confidence correlation was persistent even for misleading problems, like Example 1 above, for which fluency is not related to success and is thus a non-diagnostic cue to confidence.

The negative correlation between metacognitive judgments and fluency is often explained by positing reliance on a fluency heuristic that works in a bottom-up fashion (e.g., Ackerman & Zalmanov, 2012; Koriat et al., 2006). In contrast, Ackerman (in press) recently suggested that, in contrast to rapidly accomplished tasks, such as memorizing word-pairs, fluency may not be the only source for the persistent negative time-confidence correlation in lengthier tasks, such as problem solving. According to her Diminishing Criterion Model, the negative correlation stems from a top-down regulatory process: Lengthy engagement in solving a problem is accompanied by increasing willingness to compromise on the stopping criterion. That is, the stopping criterion diminishes over time and this leads to negative time-confidence correlations. Note that this idea does not rule out fluency effects. It is possible that both a bottom-up fluency and top-down shifting of the stopping criterion jointly contribute to a negative time-confidence correlation.

These findings raise the question of whether the negative time-confidence correlations observed when answering knowledge questions (Ackerman & Koriat, 2011; Kelley & Lindsay, 1993) might also reflect top-down regulatory processes, above and beyond bottom-up effects of fluency. Thus, just as it is possible to draw useful analogues from meta-memory to meta-reasoning, findings about meta-reasoning may provide useful hypotheses about potentially similar processes in meta-memory.

Conclusions

Although reasoning processes evolve over a much longer time period than required for memorization or retrieval, the principles of meta-memory have nonetheless provided a useful starting place to theorize about meta-reasoning. For example, it seems clear that meta-level judgments in both domains are based, at least in part, on heuristic cues, such as fluency. Thus, the accuracy of meta-reasoning judgments, like their meta-memory counterparts, is determined by the validity of the cues on which they are based, so that judgments of reasoning performance, like judgments of memory, may be very inaccurate (Ackerman & Zalmanov, 2012; De Neys et al., 2013; Prowse Turner & Thompson, 2009; Shynkaruk & Thompson, 2006). On the other hand, the fact that reasoning unfolds over a longer period of time means that the contribution of those cues to meta-judgments may be different. For example, Vernon and Usher (2003) found that although initial dPOK judgments were higher for familiar than unfamiliar items, this difference disappeared over time and Ackerman (in press) found that bottom-up fluency might be less dominant in problem-solving situations than is posited to be the case for memory.

Indeed, one of the main challenges for meta-reasoning research, going forward, will be to examine how people monitor their progress during lengthy reasoning tasks, and how they decide to allocate effort to that task. A promising starting point is the discrepancy reduction model initially proposed by Nelson and Narens (1990), which suggests that reasoners continue to invest time and effort in a task until a threshold of confidence has been reached. Once again, the fact that reasoning unfolds over a long period of time means that the process may operate quite differently in reasoning than in memory. That is, in reasoning, Ackerman (in press) has shown that one way that reasoners can achieve the target threshold is simply to lower it!

It is clear from our review that meta-reasoning judgments play an important role in regulating object-level processes, as is the case for meta-memory judgments. Both Thompson (Thompson et al., 2011, 2013) and Ackerman (Ackerman, in press) have shown that judgments such as FOR and intermediate confidence judgments are related to the amount of subsequent effort that reasoners invest in a task. A promising direction for future work will be to examine this relationship in more detail to see how such meta-reasoning judgments are related to strategy choice. For example, in cases where there is a strong, initial level of confidence or FOR, reasoners may engender a relatively superficial form of analysis, such as rationalization of the initial answer, whereas lower levels of initial confidence may result in strategies aimed at finding an alternative solving approach (Thompson, 2009).

Finally, we hope that the issues raised, the methodologies we reviewed, and the directions we pointed to will stimulate future meta-reasoning and meta-memory research. There are, moreover, tasks in related fields, such as judgment and decision-making, that are seldom studied through a metacognitive lens. In some cases, the analogy may be easy, as dual process models have been widely applied to decision-making tasks, making the link with the framework we have developed here (Kahneman, 2011). However, decision making can also involves quite different tasks, such as medical diagnosis (e.g., Norman & Eva, 2010), professional self-regulation (e.g., Dunning, Heath, & Suls, 2004), the challenges investigators face in forensic contexts (e.g., Lindsay, Nilsen, & Read, 2000), and organizational decisions (e.g., See, Morrison, Rothman, & Soll, 2011). In these tasks, errors in monitoring may have critical consequences. In theory, this should influence metacognitive processes by inducing people to set high confidence thresholds and critical self-assessment of the ongoing process. Does it really happen? and if so, under what conditions? Moreover, we know very little about metacognitive monitoring and regulation of open-ended decisions, like choosing among several products (e.g., Alba & Hutchinson, 2000) and other financial decisions (e.g., Biais, Hilton, Mazurier, & Pouget, 2005). As we argued above with regard to text learning, vagueness in the target state may produce a low correspondence between metacognitive judgments and decision outcomes, as assessed by external criteria. Metacognitive processes in creative tasks, such as writing (e.g., Harris, Graham, MacArthur, Reid, & Mason, 2011) and design (e.g., Adams, Turns, & Atman, 2003), are likewise poorly understood. We hope that the analogy we made between meta-reasoning and meta-memory will inspire research into these and others tasks to facilitate our understanding of the regulatory processes that are central to all cognitive tasks.

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