Chapter 6
Metacognitive Control of Learning and Remembering

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Introduction

The study of learning and memory has a long and veritable history in psychological research. One recent and important development is the growth of research in *metamemory*—the study of what people understand about their memory and how they use that knowledge to direct their own learning experiences in service of their goals. Metamemory research has been guided in part by the framework proposed by Nelson and Narens (1994), which differentiates between *metacognitive monitoring* of one's states of learning and *metacognitive control* over the processes by which one achieves desired levels of skill and memory. These processes are guided by learners' knowledge and beliefs about how memory works, about what aspects of performance are reliable indicators of durable learning, and about what actions are effective for advancing learning (cf. Dunlosky & Hertzog, 2000; Hertzog, Dunlosky, & Robinson, 2007).

This chapter will discuss the role of metacognition in the learning of simple verbal materials, with a particular emphasis on metacognitive control. Learners can regulate their study experience to enhance learning in a myriad of ways (cf. Benjamin, 2008; Dunlosky, Serra, & Baker, 2007; Serra & Metcalfe, 2009). Here we consider forms of control that have been studied in simple laboratory tasks and that generalize in a straightforward way to options available to students studying for tests: self-pacing study effectively, devising efficient study schedules, judiciously selecting items for study and re-study, strategically making use of self-testing strategies, accommodating study to anticipated test conditions, and using successful retrieval strategies. We will review research that reveals how learners use these strategies in simple laboratory tasks and that suggests how such metacognitive skills can be improved through instruction or experience. We will end by addressing the supportive role that information technology can play in the processes by which metacognition influences learning and memory.

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Interplay Between Metacognitive Monitoring and Control

In this section, we review evidence on the relationship between monitoring and control. The effective control of learning behavior requires accurate assessments of current states of knowledge (Benjamin, Bjork, & Schwartz, 1998; Benjamin, 2005; Konopka & Benjamin, 2009), the current rate of learning (Metcalfe & Kornell, 2005), the effects of various stimulus factors on learning (Benjamin, 2003), the effectiveness of competing strategies in promoting additional learning (Benjamin & Bird, 2006; Son, 2004), the nature and payoff structure of the upcoming test (Benjamin, 2003; Dunlosky & Thiede, 1998), and the exact form of the learning function for the particular study material (Son & Sethi, 2006).

Metacognitive monitoring is theorized to directly impact control of learning behavior. According to the "monitoring affects control" hypothesis (Nelson & Leonesio, 1988), objective item difficulty influences a person's beliefs about item difficulty, which in turn influence control processes such as study time allocation, item selection, retrieval strategies, and output decisions.

Monitoring of Ongoing Learning

The most prominent example of monitoring affecting control comes from research on self-pacing (i.e., allocation of study time). The *discrepancy reduction* model of self-pacing (Thiede & Dunlosky, 1999) suggests that learners set a desired state of learning, continuously monitor their current state of learning while studying, and only stop studying when their current state meets or exceeds the desired state. As this model predicts, learners usually do allocate more study time to material judged as more difficult, across a wide range of circumstances—from children to older adults (Dufresne & Kobasigawa, 1988, 1989; Kobasigawa & Metcalf-Haggert, 1993), from recognition to free recall tasks (Belmont & Butterfield, 1971; Le Ny, Denheire, & Taillanter, 1972; Zacks, 1969), and from simple to complex study materials (Baker & Anderson, 1982; Maki & Serra, 1992; Son & Metcalfe, 2000).

Another position on how learners choose to self-pace learning of differentially challenging materials is the *region of proximal learning* hypothesis, which posits that learners preferentially allocate study time not to items that are furthest from their current grasp (as specified by the discrepancy reduction model) but rather to items that are just slightly beyond their current grasp. According to this hypothesis, learners monitor their current *rate* of learning and continue to study items until that rate drops below a pre-determined threshold. This contrasts with the discrepancy reduction model, in which learners study until the item reaches a pre-determined *level* of learning. Research on the influence of domain expertise and on the influence of learning goals supports aspects of the region of proximal learning hypothesis: experts allocate their study time to more difficult items than do novices, and conditions inducing low performance goals (e.g., time pressure or penalties for remembering too many items) lead learners to spend more time on easy items, abandoning the more difficult items (Thiede & Dunlosky, 1999; Son & Metcalfe, 2000).

For the purposes of this chapter, the critical aspect of both theories is that they incorporate a predominant role for the monitoring of ongoing learning in determining what to study and how to distribute study time across materials.

Judgments of Learning as an Index of Current Learning

One difficulty in evaluating how learners operate upon materials of varying difficulty is the presence of idiosyncratic differences in knowledge and intellectual skills. What is difficult for one learner may be easy for another, for a variety of reasons relating to their constitution and experience. In research on metacognition, this problem is often addressed by asking learners to make explicit assessments of their level of learning; such *judgments of learning* (JOLs) are reflective of normative difficulty (e.g., Dunlosky & Matvey, 2001) and show reasonable correlations with learners' later test performance (e.g., Arbuckle & Cuddy, 1969; Dunlosky & Nelson, 1992, 1994; Lovelace, 1984). Although there are numerous cases in which JOLs are dissociable from actual learning (e.g., Benjamin, 2003, 2005; Benjamin & Bjork, 1996; Benjamin et al., 1998; Finn & Metcalfe, 2008; Schwartz & Metcalfe, 1994; Metcalfe, Schwartz, & Joaquim, 1993), subjective JOLs are likely to be a reasonable proxy variable for a learner's objective current learning state under most conditions.

In a meta-analysis of published research examining the relationship between JOLs and study time allocation, Son and Metcalfe (2000) found that 35 out of 46 published papers revealed a negative correlation: learners devote more time to items they have rated as the least well learned. In addition, choice of items for re-study is related to learners' JOLs: when given the option of re-studying a portion of previously studied materials, learners typically choose to re-study those items to which they gave the lowest JOLs (Nelson, Dunlosky, Graf, & Narens, 1994). Even in situations where JOLs are unrelated to final recall performance, learners choose to re-study items based on their JOLs and not on their ultimate recall performance (Finn & Metcalfe, 2008). Such evidence suggests that learners control their studying based on the results of their monitoring, generally choosing to re-study and spend more time on items they have judged most difficult to remember.

Monitoring of Retrieval Processes and Control of Output

Monitoring has also been found to influence control at the time of retrieval. For example, when learners give high *feelings of knowing* to unrecalled answers—that is, high judgments of knowing the answer even though they cannot currently recall it—they are willing to search memory for a longer period of time (Costermans, Lories, & Ansay, 1992; Nelson & Narens, 1990). A similar process appears to underlie how learners respond to general information questions. An initial, rapid feeling of knowing guides a strategic choice: if they think they have enough relevant knowledge, learners will try to directly retrieve the answer from memory, but if they do not think they have enough relevant knowledge, they will instead try to compute a plausible answer from a set of related facts stored in memory (Reder, 1987).

After learners find an answer in their memory or derive a plausible one from relevant knowledge, they control whether to withhold or report the answer. This decision is greatly influenced by another form of monitoring: their *confidence* in the answer. A strong correlation has been found between subjective confidence in the correctness of an answer and the willingness to report that answer (Koriat & Goldsmith, 1996). When forced to provide a response for every general knowledge question posed, learners report more answers but have lower overall accuracy compared to learners who are allowed to respond with “I don’t know.” This shows that under “free report” circumstances, learners selectively withhold low confidence answers in order to boost their overall accuracy. Furthermore, learners shift their confidence criteria for reporting answers in response to external reward structures, suggesting that learners have great control over which answers they report. Learners are willing to report lower confidence answers when external incentives reward quantity over accuracy but withhold these lower confidence answers when the external incentives reward overall accuracy instead of quantity.

The Study of Metacognitive Control

In laboratory experiments, the relative effectiveness of metacognitive control is evaluated by comparing memory performance following learner-based versus experimenter-based control of some aspect of study. The implicit assumption in such a comparison is that learners seek primarily to maximize performance. It is worth noting, however, that students and other learners outside the laboratory may have more complex goals. Such learners have constraints on the time they have to spend (Son & Metcalfe, 2000) and the effort they are willing to expend and may be seeking to satisfice rather than optimize (Simon, 1957).

Given this complex interplay of goals and abilities, as well as the high demand for effective metacognitive monitoring, it is all the more impressive that there is a wealth of results indicating that metacognitive control is widely used and often quite effective. The next portion of this chapter will focus on examples of such metacognitive control.

Effectiveness of Metacognitive Control

Self-Pacing of Study

One way of assessing the value of metacognitive control is to evaluate the efficacy of self-paced study (or study-time allocation). As discussed earlier, learners usually devote more time to the items which they judge to be most difficult; however, spending additional time studying difficult material sometimes results in no benefit for memory of those items (labeled the "labor in vain" effect, cf. Nelson & Leonesio, 1988). It is not obvious that allowing learners to self-pace can improve their performance compared to controls who do not self-pace. In a study by Koriat, Ma'ayan, and Nussinson (2006), learners either self-paced their study of a word list or spent the same amount of time studying the words but were forced to view words for uniform amounts of time across items. Self-pacing did not lead to any significant improvement in performance on a cued recall task. However, using a recognition task (a more sensitive measure of memory), Tullis and Benjamin (2009) found that learners who were allowed to allocate their own study time performed significantly better than did learners forced to spend uniform amounts of time across items. Interestingly, the improvement in memory performance was found only for learners who allocated more time to the normatively difficult items at the expense of the easy items. This result demonstrates that the net effect of self-control over the pace of study can benefit performance, but only for learners who engage in an effective allocation strategy.

There is also evidence that the effectiveness of study time allocation increases with age and expertise. Liu and Fang (2005) found that older grade school students were more selective about which items they spent more time studying and that free recall performance correspondingly increased with age. Liu and Fang (2006) found that older students spent less time on easy items and more time on difficult items as compared to younger students. Metcalfe (2002) found a difference in the way novices versus experts allocated study time across English–Spanish word pairs of varying difficulty. Both groups appear to selectively allocate time to unlearned items that were closest to being learned. For the experts (self-identified Spanish speakers), those were the most difficult items; for the novices, those were items that were somewhat easier.

Devising Study Schedules

Although strategically scheduling one's own study is a common activity, few experiments have investigated how learners do so in laboratory tasks. One important aspect of scheduling that has received some attention is the temporal distribution of multiple study trials for the same item. It is well established that spacing out such trials, rather than massing them together, results in superior memory performance at a delay (cf. Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006). Son (2004) investigated learners' tendency to effectively employ spacing. Learners were presented with synonym word pairs (e.g., "hirsute—hairy") for 1 s each. After each presentation, learners made a JOL, then chose whether to re-study the pair immediately, at a delay, or not at all. Finally, learners were given a cued recall test after a 15-min delay. Results showed that learners scheduled re-study based on their metacognitive monitoring, tending to space items they judged as harder and mass items they judged as easier. Thus, in contrast to findings on self-pacing that support the discrepancy reduction model, learners used the more effective scheduling strategy (spacing) on less difficult items. However, Benjamin and Bird (2006) found the opposite effect when they increased initial presentation time to 5 s and added the constraints that all pairs be restudied, half massed and half spaced. Toppino, Cohen, Davis, and Moors (2009) sought to elucidate these discrepant findings by manipulating initial presentation time (1 vs. 5 s). They found that learners tended to space harder pairs when given more time and vice versa when given less time. The preference for massed re-study in the 1 s condition appeared to arise from inadequate time to fully perceive the pair, which happened more often for pairs consisting of longer and lower-frequency words (i.e., the harder pairs). When given enough time for initial encoding, learners indeed employ effective scheduling for more difficult material.

Selection of Items for Study and Re-study

Learners make sensible decisions about which items they should re-study (or drop from studying), but are overly optimistic about their final level of memory performance. Kornell and Metcalfe (2006) gave learners a list of general knowledge facts to study once. Learners then decided which half of the items they needed to re-study, and these decisions were either honored (learners re-studied the items they selected) or dishonored (learners studied the items they did not choose). Honoring learners' choices about which items to re-study led to greater final test performance than did dishonoring those choices. This demonstrates that learners can make reasonable choices about which items to re-study and that giving learners control over their own study can improve memory performance.

However, giving learners more control over item selection does not always lead to better performance. Kornell and Bjork (2008) and Atkinson (1972) showed that learners with less control over which items they re-studied outperformed those with more control. In the study by Kornell and Bjork, some learners were allowed to drop English–Swahili word pairs from their study routine, while others had no choice but to re-study the entire list of pairs. Allowing learners to drop items from their study routine generally hurt performance (compared to making the learners re-study the entire list of items) on a final cued recall test, both immediately and at 1 week delay, even when the groups were given the same overall amount of study time. In combination with the Kornell and Metcalfe study (2006), this shows that learners are effective at choosing which items they need to re-study, but overly optimistic about their ability to recall information later. Atkinson evaluated memory performance under conditions in which item selection was controlled by learners, determined randomly, or determined by an experimenter-designed adaptive algorithm. He found that performance by the self-controlled group was higher than the random group, but lower than the algorithm group. Thus, learners choose items for re-study effectively to some extent but less than optimally.

Strategic Use of Self-Testing

Kornell and Son (2009) investigated the extent to which learners would employ self-testing when studying word pairs using a flashcard-like paradigm. After an initial presentation, learners could chose to either re-study all items or receive a practice test on all items. They more often chose to self-test, which produced greater final test performance than did re-study. Curiously, however, learners rated re-study as more effective. This, along with survey data (cf. Kornell & Bjork, 2007) suggests that learners may choose self-testing not out of a belief that it will directly enhance memory but rather as a useful tool for self-assessment.

Accommodating Study to Anticipated Test Conditions

Learners' expectations about the format of an upcoming test influence the way they study (a.k.a. encoding strategy) and their ultimate performance. For example, learners expecting a recall test have been found to outperform learners expecting a recognition test on a final test of either format (cf. Neely & Balota, 1981). Kang (2009) investigated learners' tendencies to choose different forms of self-testing as a form of practice and whether that tendency could be improved. Learners studied Malay–English word pairs, and when explicitly presented with study options that included practice cued recall or practice multiple choice, learners more frequently chose the study option that matched the test format they were induced to expect. On a final cued recall test after a 2 day delay, learners who had chosen practice cued recall outperformed those who had chosen practice multiple choice, demonstrating the effectiveness of their self-testing choice.

Although learners do appear to tailor their encoding strategies toward the expected demands of an upcoming test, they do not always do so effectively. In a study by Finley and Benjamin (2009) learners studied word pairs across multiple study-test cycles. One group received free recall tests for only the target (right-hand) words. Even after an initial study-test cycle, these learners still employed unhelpful strategies, such as attending to the relationship between the left- and right-hand words. However, as we will detail later, their use of an appropriate encoding strategy did improve with further experience.

Retrieval Strategies

Metacognitive control may be exercised during retrieval as well as encoding. For example, in a typical laboratory free recall test, learners may output items in any order, thus allowing them to implement whatever retrieval strategy they wish. In a serial recall test, learners are instead forced to output items in a specific order (typically the same order in which items were presented), reducing the amount of control they can exercise over their retrieval processes. Several studies have found that total recall is lower for immediate serial recall tests than for immediate free recall tests (Bhatarah, Ward, & Tan, 2008; Earhard, 1967; Klein, Addis, & Kahana, 2005; Waugh, 1961). This result demonstrates that, left to their druthers, people choose an output strategy that increases performance relative to having no control over output order.

Taken together, the results in this section speak both to the basic effectiveness of learners' metacognitive control and to implications for improving control. That is, learners are generally effective at controlling study, but there is room for improvement.

Improving Metacognitive Control

Improving Monitoring

To improve memory performance, one can focus on metacognitive monitoring or control. Superior evaluation of what is likely to be difficult and what is likely to be easy can enable more effective allocation of one's time and resources, even as one's control policy remains consistent.

One way of increasing the accuracy of metacognitive monitoring is to delay judgments until some time after study, rather than making them immediately following study (Nelson & Dunlosky, 1991), and furthermore to make judgments without looking at the complete answer, thus encouraging active retrieval of relevant information from memory (Dunlosky & Nelson, 1992). Thiede, Anderson, and Therriault (2003) extended these results to a more complex task. They found that generating keywords after reading a text passage led to more accurate self-ratings of text comprehension compared to no keyword generation, and this advantage was even greater when keyword generation was done at a delay. Furthermore, the more accurate monitoring was followed by more strategic choices of which texts to re-study and higher scores on a final test. Thus, a condition which improved metacognitive monitoring also promoted more effective study choices. Dunlosky, Hertzog, Kennedy, and Thiede (2005) reviewed other data showing enhanced performance resulting from improvements in metacognitive monitoring.

Improved metacognitive monitoring may enable more effective implementations of control processes. But a focus on directly improving metacognitive control may also be an effective way to improve learning.

Improving Control at Encoding Via Direct Instruction

It is well known that learners can follow instructions (a.k.a. "orienting tasks") to encode or retrieve material differently, resulting in changes in performance. For example, Craik and Lockhart (1972) demonstrated that semantic ("deep") encoding of words, such as deciding whether each word would fit into a category or not, led to superior subsequent memory performance versus more "shallow" encoding, such as making judgments about a word's font.

Another relevant principle in human learning and memory is that of *transfer-appropriate processing*: memory performance is enhanced to the extent that mental processes at encoding and retrieval are similar. This principle suggests that effective encoding strategies are those that employ processes most closely matching those that will be used at the time of retrieval. This is borne out in a study by Morris, Bransford, and Franks (1977). In that study, learners were presented with single words that were each preceded by an orienting sentence that either induced semantic processing (e.g., "The—had a silver engine." ... "TRAIN") or phonetic processing (e.g., "– rhymes with legal." ... "EAGLE"). Learners responded "yes" or "no" to each item, either judging whether the word was appropriate in the sentence or judging whether the word indeed rhymed. Learners were then given either a standard recognition test for the originally presented words or a recognition test for words that rhymed with the original words. For the standard recognition test (which presumably induces more emphasis on the meaning of words), performance was highest for items that had undergone semantic processing at encoding. However, for the rhyming recognition test, performance was highest for items that had undergone phonetic processing at encoding. Thus, performance on each test type was superior for items that had been processed in a transfer-appropriate way at encoding.

Learners can also be instructed to use various *mnemonic* strategies to enhance learning (Bellezza, 1996). For example, Roediger (1980) instructed learners to study word lists using elaborative rehearsal (repeating each word and its meaning to themselves multiple times), visual imagery for each word, visual imagery that linked words, the loci method (imagining each word in a familiar sequential location), or the peg method (associating each word with a pre-learned sequence of "peg" words, such as "gun" for position one). On immediate and 24-h delayed tests, learners were instructed to try to recall words in the same order that they had been studied. The linked imagery, loci, and peg mnemonics led to greater performance than elaborative rehearsal and individual imagery, in terms of total number of words recalled, and especially words recalled in their correct order. This demonstrates that learners can capably employ metacognitive control processes from direct instruction and that these acts can enhance learning, particularly when such processes are well-suited for the retrieval task (although the costs of such strategies may be worth considering as well; e.g., Benjamin & Bjork, 2000).

Improving Control at Encoding via Experience

To what extent can metacognitive control be improved via experience rather than instructions? Relevant research here has chiefly used multiple study-test cycles to investigate changes in metacognitive control. Repeated exposure to the conditions of study and test can lead learners to adopt more effective control strategies, particularly when they are also assisted in assessing their own performance as a function of the control processes they implement.

Postman (1964) found that learning improved across a series of unrelated word lists as learners acclimated to the task, a phenomenon he dubbed “learning to learn.” It is also clear from studies of intentional versus incidental learning that knowledge at all of an upcoming test can change the way learners encode information, though specific knowledge about the test format may do so more potently (McDaniel, Blischak, & Challis, 1994). What changes in metacognitive control of study may give rise to such effects?

Learners have been shown to adjust their amount of study after experience with the nature of the material and the demands of the test. For example, d’Ydewalle, Swerts, and De Corte (1983, Experiment 2) had learners study a passage of text for as long as they wanted, followed by either a fill-in-the-blank test or a multiple choice test. Learners were led to expect that they would receive the same test format for a second study-test cycle (using a new text passage of the same length). Learners spent more time studying the passage in the second cycle than they had during the first cycle. Furthermore, they spent more time if they expected a fill-in-the-blank test versus a multiple choice test. These changes in study duration were appropriate considering that performance on the first test was rarely perfect and that the fill-in-the-blank test was more difficult than the multiple choice test.

Finley and Benjamin (2009) evaluated learners’ abilities to adaptively modify their encoding strategies to better reflect the demands of upcoming tests as they gained more experience with the tests. Across four study-test cycles, learners were induced to expect either cued or free recall tests by studying lists of word pairs and receiving the same test format for each list. Tests required recall of the target (right-hand) words either in the presence (cued recall) or in the absence (free recall) of the cue (left-hand) words. A fifth and final cycle included either the expected or the alternate, unexpected test format. On both cued and free recall final tests, learners who had expected that format outperformed those who had not expected it, as shown in Fig. 6.1. Furthermore, on subsequent tests of recognition, cued-expecting learners showed superior recognition of cue words and superior associative recognition of intact word pairs, with such recognition decreasing across lists for free-expecting learners. These results demonstrate that learners were not merely modulating study *effort* based on anticipated test difficulty but were adopting qualitatively different encoding strategies that were appropriate to the demands of the expected test. Specifically, free-expecting learners learned to attend predominantly to the target words, abandoning the cue-target associative strategy with which they had begun.

In another experiment, Finley and Benjamin (2009) investigated adaptive changes in control of self-paced study. Learners were allowed to control study time across three cued recall and three free recall study-test cycles. They were instructed as to the nature of each upcoming test before they began the study. Importantly, each cycle included word pairs of both high and low associative strength, a variable that affected performance for cued recall (higher recall for high associative strength pairs) but not free recall. Learners began the task by allocating more study time to pairs with low associative strength when expecting either test format. As shown in Fig. 6.2, learners continued this pattern of allocation across cued-recall study-test

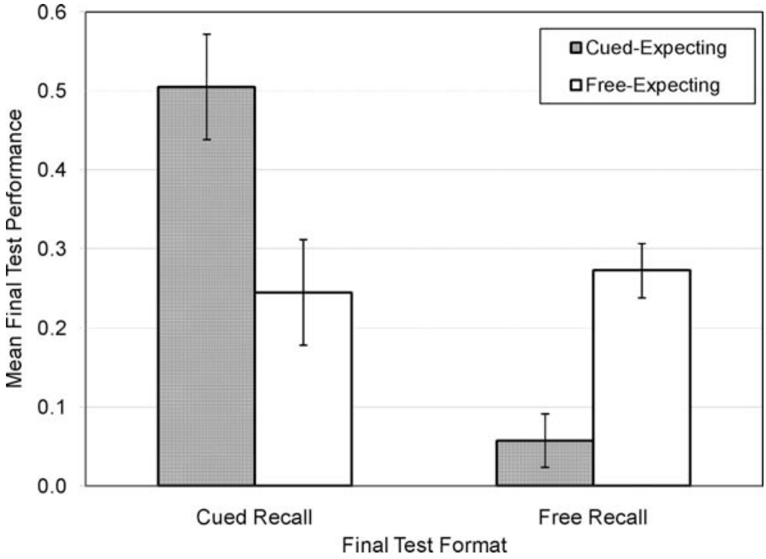

Fig. 6.1 Mean final recall performance as a function of actual final test format (cued vs. free recall) and expected test format (cued vs. free recall). Error bars represent standard error pooled within final test format

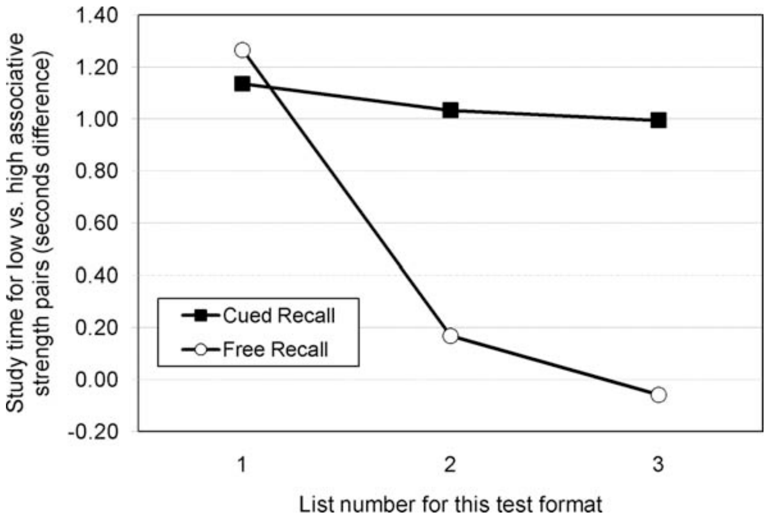

Fig. 6.2 Mean study time allocation (seconds) for low versus high associative strength word pairs (difference in learner medians) as a function of expected test format (cued vs. free recall) across three study-test cycles

cycles but decreasingly differentiated between high and low associative strength pairs across free recall study-test cycles. Thus, experience with the nature of a specific test format and the effectiveness of their metacognitive control led learners to increasingly adopt more effective encoding strategies and study-time allocation strategies.

Another demonstration of improved metacognitive control via experience is provided by deWinstanley and Bjork (2004). They investigated the possibility of enhancing learners' sensitivity to the advantages of generating versus reading to-be-learned words. The generation effect (Slamecka & Graf, 1978) is the well established finding that information generated by a learner tends to be better remembered than information merely read by the learner. In the experiments by deWinstanley and Bjork, learners completed two study-test cycles. Materials were sentences from an introductory psychology textbook in which critical words were either printed in red in their entirety (read condition) or printed in red with several letters missing (generate condition). Tests were fill-in-the blank recall that used previously studied phrases from which critical words had been removed and did not provide feedback. Results of the first experiment indicated that when learners were given a chance to experience the differential performance benefits (on the first test) for generated versus read items, they improved their subsequent performance (on the second test) for read items to the level of the generated items; this suggests that learners spontaneously, and adaptively, changed the way they processed the read items. This result was not obtained when learners were not given the critical experience, such as when reading versus generating was manipulated across the two study-test cycles or across learners.

In addition to finding that learners preferred to self-test over re-study as described earlier, Kornell and Son (2009) found that across experience with multiple study-test cycles, learners learned to self-test themselves more and did so at a faster rate when there was feedback on the tests at the end of each cycle. Because self-testing indeed produced higher performance, this study showed that learners' metacognitive control became more effective with experience.

Kang (2009) also investigated whether learners would tend to self-test more with experience. In this follow-up to the experiment described earlier, learners completed two study-test cycles. In the first cycle, following an initial presentation, items were either represented, practiced via cued recall, or neither. Learners were either given a cued recall test at a 2-day delay or given no test for this cycle. In the second study-test cycle, following initial presentation, learners were allowed to choose how to practice each item: representation, cued recall, or no practice. Learners who had received the cued recall test following the first list chose the recall practice option more frequently than did learners who did not receive that test. Furthermore, Kang found that learners who had experienced a large advantage for recalled over represented items on that test chose cued recall practice more frequently in the second cycle, revealing that the experience at test of the downstream benefits of self-testing practice was the central factor promoting later choice of that strategy.

Improving Control at Retrieval Via Direct Instruction

Although research on improving self-directed learning has largely emphasized processes at encoding, there is also potential for making improvements at retrieval (cf. Adams, 1985).

In recognition memory tasks, learners study a list of items and are later given a test containing some studied items and some unstudied items. Their task is to identify the studied items as "old" and the unstudied items as "new." Each individual's performance consist of two components: the sensitivity of his or her memory to this distinction and his or her response bias (a.k.a. criterion): a tendency to say "old" more often than "new" or vice versa (for further discussion see Rotello and Macmillan, 2008). Postma (1999) found that response bias can be manipulated via instructions to respond liberally (to say "old" if "they had even only a weak notion that they had studied it previously") or conservatively (to say "old" only to items for "which they were very certain").

Reder (1987) presents evidence that learners can make use of different strategies in answering questions about material they have learned. Specifically, they may use a strategy of directly retrieving specific information from memory to answer the question or a strategy of inferring an answer based on the gist of the material or on related retrieved information. In one experiment, learners read short stories (e.g., about a village in Burma that hires a hunter to kill a man-eating tiger) and were then given sentences that had either been presented in the story or not and that varied in their plausibility in the overall context of the story (e.g., "The villagers were afraid of the tiger" [plausible] and "The villagers make their living primarily by hunting" [implausible]). The task for each sentence was to judge whether it was plausible or implausible. Each sentence was also preceded by advice on which strategy to use: either to "try to retrieve a specific fact to use in judgment" or to "try to infer the answer." Advice was manipulated within-subjects on an item-by-item basis. Results showed that advice to infer led to greater sensitivity (as measured by response time) to the plausibility of the sentence than did advice to retrieve, while advice to retrieve led to greater sensitivity to whether the sentence was presented or not than did advice to infer. Furthermore, performance was enhanced when the advice given was appropriate (retrieve advice for items actually presented and infer advice for items not presented). These results demonstrate that learners can indeed use their memories differently in response to instructions, and this can influence their performance.

Williams and Hollan (1981) described numerous retrieval strategies spontaneously used as learners tried to recall as many names as possible of classmates from high school. A number of these strategies have been experimentally demonstrated to be effective in improving the amount of accurate recall. One such strategy is the adoption of more than one perspective at retrieval. In a study by Anderson and Pichert (1978), learners read a brief story about a house after first being instructed to adopt the perspective (a.k.a. schema) of a burglar, or of a homebuyer. After a 12-min delay, learners were given a first free recall test, on which they were instructed to write down as much of the story as they could remember. After another delay of 5 min, learners were given a second free recall test, on which they were either reminded of the perspective they had been given at reading or instructed to adopt the alternative perspective. Learners who were instructed to switch perspective for the second test recalled more information important to the new perspective than did learners who were instructed to keep the same perspective (see also Surber, 1983).

Reinstating the context of learning is another strategy that can enhance retrieval. In a study by Smith (1979), learners studied a word list in one room and were later tested either in the same room or a different one. Being tested in the original room yielded higher free recall performance than did being tested in the different one, demonstrating the effect of environmental context (Bjork & Richardson-Klavehn, 1989). Interestingly, Smith also found that instructing learners to mentally reinstate the original room enhanced performance to the same extent as actually testing them in the original room.

In addition to reinstatement of context, retrieval can also be improved by reinstatement of processing. Recall the principle of transfer-appropriate processing, reviewed earlier. Just as performance is enhanced when learners employ an encoding strategy appropriate for a particular test, performance should also be enhanced when learners employ retrieval strategies consistent with the way information was encoded. This is borne out in a study by Fisher and Craik (1977). Learners were presented with single words that were each preceded by one of three orienting questions: whether the target word rhymed with a particular other word, whether the target word fit into a particular category, or whether the target word fit into a particular sentence. Learners were then given a cued recall test in which each target word was cued by either the same type of question used for that word at encoding or one of the two alternative question types. For each of the three encoding conditions, performance was highest when the retrieval cue was of the same type as that used at encoding. These results, considered alongside those from Morris et al. (1977), demonstrate that instructing subjects on compatible means by which to encode and retrieve studied information can have a big effect on performance, suggesting that choosing a learning strategy to match the upcoming task, or a retrieval strategy that matches the prior learning, is an effective means of enhancing performance. It remains to be seen whether learners can do so effectively in the absence of direct instruction.

Finally, we consider an applied example of improving metacognitive control at retrieval via direct instruction. The cognitive interview (Fisher & Geiselman, 1992) is a technique for questioning eyewitnesses to crimes that has been found effective in increasing the amount and accuracy of recalled information (Geiselman et al., 1984). It incorporates a number of effective retrieval strategies, including reinstating physical and mental context, minimizing distractions, encouraging multiple and extensive retrieval attempts, and requesting retrieval in multiple temporal orders and from multiple perspectives.

Improving Control at Retrieval Via Experience

Just as learners can be induced via instructions to shift their response bias in a recognition task, they have also been shown—in some circumstances—to adaptively adjust their bias across experience with a task. For example, Benjamin (2001; see also Benjamin & Bawa, 2004) found that presenting a word list three times, rather than only once, led young adult learners to adopt a more conservative response bias and thus to less frequently falsely endorse unstudied items that were highly related to studied items. Han and Dobbins (2009) found that learners shifted their bias in response to experience with misleading feedback. Learners who were told that they were correct when they replied "new" to a studied item adopted a more conservative bias (increasing misses), while learners who were told that they were correct when they replied "old" to an unstudied item adopted a more liberal bias (increasing false alarms). However, whether a learner engages in a response bias shift and whether that shift increases accuracy depends on a host of as-yet unidentified factors, and there are numerous cases in which such strategic shifts are not obtained (Healy & Kubovy, 1977; Stretch & Wixted, 1998).

In free recall tests, learners tend to output the most recently studied items first (Deese & Kaufman, 1957). Furthermore, learners increasingly adopt this retrieval strategy across experience with multiple study-test cycles (Huang, 1986; Huang, Tomasini, & Nikl, 1977). This effect can be seen as learners learning to take advantage of the fact that not only are the most recently studied items better recalled than older items on an immediate test (Murdock, 1962), but this recency effect quickly evaporates (Jahnke, 1968). This would be consistent with the findings of Castel (2008): learners' JOLs reflected an improved appreciation for serial position effects (the benefits of primacy and recency) when learners were given experience across multiple study-test cycles and when serial position was made salient by either collecting JOLs prior to presenting each item or by explicitly presenting each item's serial position during study.

When a subset of studied material is again presented at a free recall test, ostensibly to help the learner remember the rest of the material, these cues can actually impair that performance. This is known as the part-list cuing or part-set cuing effect (e.g., Nickerson, 1984). Liu, Finley, and Benjamin (2009) investigated whether learners would come to appreciate the potentially deleterious effects of part-list cues across five study-test cycles in which learners were allowed to choose how many cues they would receive on the test. In each cycle, learners first studied a list of 30 words presented one at a time. At the end of this presentation, learners chose how many of the words (from 0 to 15) they wanted to be given as cues on the test to help them remember the rest of the words. Finally, learners were given a free recall test that represented the number of cues they had requested and instructed learners to recall the non-cue words. Learners indeed chose fewer cues across cycles, demonstrating a strategic improvement in their choices of testing condition. This is consistent with work by Rhodes and Castel (2008) which showed that learners' predictions of their own memory performance (JOLs) were only sensitive to the detriments of part-list cuing after experience with the task.

Role of Information Technology

Implementing Metacognitive Control

Actually executing what is good for learning can be onerous. Thus, information technology can be used to implement effective metacognitive control on behalf of the learner. A cornucopia of software programs, sometimes termed "computer-based learning environments," have been developed with the aim of assisting learning by, among other strategies, automating metacognitive control processes (Clark & Mayer, 2008; Lajoie, 2000; Linn, Davis, & Bell, 2004). We summarize here two examples that have been inspired by research in cognitive psychology.

SuperMemo (http://www.supermemo.com) is a program that automates scheduling of review for pieces of information (e.g., foreign language vocabulary) that the learner wants to remember indefinitely (cf. Wolf, 2008). The review trials administered by the program are similar to flashcards: cued recall followed by feedback plus the learner's self-assessment of his or her answer. SuperMemo leverages the benefits of spaced rehearsal to not only enhance learning but also to make it more efficient. It implements a schedule of expanding retrieval practice (Landauer & Bjork, 1978; cf. Balota, Duchek, & Logan, 2007) by which review is scheduled at short intervals soon after an item is first encoded and successively longer intervals as the item becomes better learned. By adaptively adjusting intervals based on a learner's performance, the program seeks to help learners retrieve information just before it is forgotten, when such retrieval should afford the most benefit (Bjork & Bjork, 1992; Wozniak & Gorzelañczyk, 1994). Managing, let alone optimizing, such a complex schedule of study without the aid of a computer would be daunting if not impossible.

A second example of efforts to offload metacognitive control onto software is the Cognitive Tutor program (http://www.carnegielearning.com). This program is one of a class of "intelligent tutoring systems" (for another such example, ALEKS, see Falmagne, Cosyn, Doignon, & Thiéry, 2003). The Cognitive Tutor maintains a cognitive model of the learner's present knowledge and skills, rooted in the ACT-R theory of how knowledge is represented and acquired (Anderson et al., 2004), and updates the state of the model based on the learner's interactions with the program. The program then tailors instruction to move the learner from his or her current state toward a goal state, which is defined by the curriculum designers for a particular domain (e.g., algebra). Among other pedagogical design features, the Cognitive Tutor selects material for display and problems for practice that are most appropriate based on its model of the learners' current understanding. It focuses the instruction on the learner's least developed skills, moving on to new material only when all skills in a section are mastered to a criterion. Thus it takes on the burden of judicious item selection and self-testing, which learners may not optimize on their own. Classroom experiments have found evidence that Cognitive Tutor enhances student learning compared to traditional teaching and study methods (Ritter, Anderson, Koedinger, & Corbett, 2007).

Training Metacognitive Control

A potential consequence of the approaches outlined above is to promote learning at the cost of developing improved metacognitive control skills. Such skills can be crucial for self-regulated lifelong learning beyond the structured learning environment. Note, however, that whether control skills really do need to be learned depends on one's goals and contexts; some control tasks may be best relinquished to the environment. Nevertheless, another approach is for information technology to guide learners toward improved metacognitive control: that is, to help learners learn how to learn.

The Cognitive Tutor program has been adapted to model, and thus also to tutor, certain metacognitive control behaviors (Koedinger, Aleven, Roll, & Baker, 2009). For example, Roll, Aleven, McLaren, and Koedinger (2007) sought to improve strategic help-seeking behavior of learners when using the built-in help functions of the Geometry Cognitive Tutor. Learners using this program had been observed to engage in maladaptive behaviors such as not seeking help at all (even after making multiple errors on the same type of problem) or quickly using the help functions to retrieve a complete answer to the current problem rather than only seeking help when they made errors or got stuck. A cognitive model of help-seeking was built, which encompassed both maladaptive and adaptive behaviors, and this was used to give learners immediate feedback when they used the help functions in suboptimal ways. There was some improvement in help-seeking under such tutelage; however, it is unclear whether learners truly developed improved skills or were merely complying with the metacognitive advice provided.

Winne and Nesbit (2009) outline important characteristics of software-enabled attempts to scaffold improved metacognition. They point out that, in addition to suggesting normatively optimal learning behaviors, educational software that logs learners' interactions (e.g., their program, gStudy) can be adapted to also present graphical representations of the strategies that learners have used and how those strategies have influenced performance. This would enable, and perhaps even motivate, learners to assess for themselves the effectiveness of their control processes—an important step in improving metacognitive control, as suggested by the data from deWinstanley and Bjork (2004).

Development of software to foster improved metacognitive control still has a long way to go (cf. Azevedo, 2007). But given that so much learning takes place outside of structured learning environments, there is much to be gained from leveraging technology to increase our self-regulated learning skills.

Summary

In this chapter, we have reviewed cognitive psychological research on self-directed learning in simple laboratory tasks. As learners monitor their own learning, they can also enhance it by exercising various forms of metacognitive control. In many cases learners do so effectively, but there is certainly room for improvement. We reviewed research suggesting a number of ways in which control can potentially be improved, at the time of encoding or retrieval, and via direct instruction or experience. Finally, we reviewed the promising role that information technology can play in implementing and training improved metacognitive control, with the ultimate goal of enhancing learning. One important lesson of research on metacognition in general is that learning can effectively be enhanced by improving our understanding of, and control over, our limited cognitive capacities.

References

Adams, L. T. (1985). Improving memory: Can retrieval strategies help? *Human Learning*, *4*, 281–297.

Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., & Qin, Y. (2004). An integrated theory of the mind. *Psychological Review*, *111*(4), 1036–1060.

Anderson, R. C., & Pichert, J. W. (1978). Recall of previously unrecallable information following a shift in perspective. *Journal of Verbal Learning & Verbal Behavior*, *17*(1), 1–12.

Arbuckle, T. Y., & Cuddy, L. L. (1969). Discrimination of item strength at time of presentation. *Journal of Experimental Psychology*, *81*(1), 126–131.

Atkinson, R. C. (1972). Optimizing the learning of a second-language vocabulary. *Journal of Experimental Psychology*, *96*, 124–129.

Azevedo, R. (2007). Understanding the complex nature of self-regulatory processes in learning with computer-based learning environments: An introduction. *Metacognition and Learning*, *2*(2–3), 57–65.

Baker, L., & Anderson, R. I. (1982). Effects of inconsistent information on text processing: Evidence for comprehension monitoring. *Reading Research Quarterly*, *17,* 281–294.

Balota, D. A., Duchek, J. M., & Logan, J. M. (2007). Is expanded retrieval practice a superior form of spaced retrieval? A critical review of the extant literature. In J. S. Nairne (Ed.), *The foundations of remembering: Essays in honor of Henry L. Roediger, III* (pp. 83–105). New York: Psychology Press.

Bellezza, F. S. (1996). Mnemonic methods for storage and retrieval. In E. L. Bjork & R. A. Bjork (Eds.), *Memory* (pp. 345–380). San Diego, CA: Academic Press.

Belmont, J. M., & Butterfield, E. C. (1971). Learning strategies as determinants of memory deficiencies. *Cognitive Psychology*, *2*, 411–420.

Benjamin, A. S. (2001). On the dual effects of repetition on false recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*, 941–947.

Benjamin, A. S. (2003). Predicting and postdicting the effects of word frequency on memory. *Memory & Cognition*, *31*, 297–305.

Benjamin, A. S. (2005). Response speeding mediates the contribution of cue familiarity and target retrievability to metamnemonic judgments. *Psychonomic Bulletin & Review*, *12*, 874–879.

Benjamin, A. S. (2008). Memory is more than just remembering: Strategic control of encoding, accessing memory, and making decisions. In A. S. Benjamin & B. H. Ross (Eds.), *The Psychology of Learning and Motivation: Skill and Strategy in Memory Use* (Vol. 48, pp. 175–223). London: Academic Press.

Benjamin, A. S., & Bawa, S. (2004). Distractor plausibility and criterion placement in recognition. *Journal of Memory & Language*, *51*, 159–172.
Benjamin, A. S., & Bird, R. D. (2006). Metacognitive control of the spacing of study repetitions. *Journal of Memory and Language*, *55*, 126–137.
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*, 55–68.
Benjamin, A. S., & Bjork, R. A. (1996). Retrieval fluency as a metacognitive index. In L. Reder (Ed.), *Implicit Memory and Metacognition*. Mahwah, NJ: Erlbaum.
Benjamin, A. S., & Bjork, R. A. (2000). On the relationship between recognition speed and accuracy for words rehearsed via rote versus elaborative rehearsal. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 638–648.
Bhatarah, P., Ward, G., & Tan, L. (2008). Examining the relationship between free recall and immediate serial recall: the serial nature of recall and the effect of test expectancy. *Memory & Cognition*, *36*(1), 20–34.
Bjork, R. A., & Bjork, E. L. (1992). A new theory of disuse and an old theory of stimulus fluctuation. In A. Healy, S. Kosslyn, & R. Shiffrin (Eds.), *From learning processes to cognitive processes: Essays in honor of William K. Estes* (Vol. 2, pp. 35–67). Hillsdale, NJ: Erlbaum.
Bjork, R. A., & Richardson-Klavehn, A. (1989). On the puzzling relationship between environmental context and human memory. In C. Izawa (Ed.), *Current issues in cognitive processes: The Tulane Flowerree Symposium on Cognition* (pp. 313–344). Hillsdale, NJ: Erlbaum.
Castel, A. D. (2008). Metacognition and learning about primacy and recency effects in free recall: The utilization of intrinsic and extrinsic cues when making judgments of learning. *Memory & Cognition*, *36*, 429–437.
Cepeda, N. J., Pashler, H., Vul, E., Wixted, J. T., & Rohrer, D. (2006). Distributed practice in verbal recall tasks: A review and quantitative synthesis. *Psychological Bulletin*, *132*, 354–380.
Clark, R., & Mayer, R. E. (2008). E-learning and the science of instruction (2nd ed). San Francisco, CA: Jossey-Bass.
Costermans, J., Lories, G., & Ansay, C. (1992). Confidence level and feeling of knowing in question answering: The weight of inferential processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 142–150.
Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning & Verbal Behavior*, *11*(6), 671–684.
Deese, J., & Kaufman, R. A. (1957). Serial effects in recall of unorganized and sequentially organized verbal material. *Journal of Experimental Psychology*, *54*(3), 180–187.
deWinstanley, P. A., & Bjork, E. L. (2004). Processing strategies and the generation effect: Implications for making a better reader. *Memory & Cognition*, *32*(6), 945–955.
Dufresne, A., & Kobasigawa, A. (1988). Developmental differences in children's allocation of study time. *The Journal of Genetic Psychology*, *149*, 87–92.
Dufresne, A., & Kobasigawa, A. (1989). Children's spontaneous allocation of study time: Differential and sufficient aspects. *Journal of Experimental Child Psychology*, *47*, 274–296.
Dunlosky, J., & Hertzog, C. (2000). Updating knowledge about strategy effectiveness: A componential analysis of learning about strategy effectiveness from task experience. *Psychology & Aging*, *15*, 462–474.
Dunlosky, J., Hertzog, C., Kennedy, M., & Thiede, K. (2005). The self-monitoring approach for effective learning. *Cognitive Technology*, *10*, 4–11.
Dunlosky, J., & Matvey, G. (2001). Empirical analysis of the intrinsic-extrinsic distinction of judgments of learning (JOLs): Effects of relatedness and serial position on JOLs. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*, 1180–1191.
Dunlosky, J., & Nelson, T. O. (1992). Importance of the kind of cue for judgments of learning (JOL) and the delayed-JOL effect. *Memory & Cognition. Special Issue: Memory and Cognition Applied*, *20*(4), 374–380.

Dunlosky, J., & Nelson, T. O. (1994). Does the sensitivity of judgments of learning (JOLs) to the effects of various study activities depend on when the JOLs occur? *Journal of Memory and Language*, *33*(4), 545–565.

Dunlosky, J., & Thiede, K. W. (1998). What makes people study more? An evaluation of factors that affect people's self-paced study and yield "labor-and-gain" effects. *Acta Psychologica*, *98*, 37–56.

Dunlosky, J., Serra, M., & Baker, J. M. C. (2007). Metamemory. In F. Durso, R. Nickerson, S. Dumais, S. Lewandowsky, & T. Perfect (Eds.), *Handbook of Applied Cognition* (2nd ed., pp. 137–159). New York, NY: Wiley.

d'Ydewalle, G., Swerts, A., & De Corte, E. (1983). Study time and test performance as a function of test expectations. *Contemporary Educational Psychology*, *8*(1), 55–67.

Earhard, M. (1967). Subjective organization and list organization as determinants of free-recall and serial-recall memorization. *Journal of Verbal Learning & Verbal Behavior*, *6*, 501–507.

Falmagne, J., Cosyn, E., Doignon, J., & Thiéry, N. (2003). The assessment of knowledge, in theory and practice. Retrieved June 14, 2009, from http://www.aleks.com/about_aleks/Science_Behind_ALEKS.pdf

Finley, J. R., & Benjamin, A. S., (2009). Adaptive changes in encoding strategy with experience: evidence from the test expectancy paradigm. Manuscript in preparation.

Finn, B., & Metcalfe, J. (2008). Judgments of learning are influenced by memory for past test. *Journal of Memory and Language*, *58*(1), 19–34.

Fisher, R. P., & Craik, F. I. (1977). Interaction between encoding and retrieval operations in cued recall. *Journal of Experimental Psychology: Human Learning and Memory*, *3*(6), 701–711.

Fisher, R. P., & Geiselman, R. E. (1992). *Memory-enhancing techniques in investigative interviewing: The cognitive interview*. Springfield, IL: C. C. Thomas.

Geiselman, R. E., Fisher, R. P., Firstenberg, I., Hutton, L. A., Sullivan, S. J., Avetisssian, I. V., et al. (1984). Enhancement of eyewitness memory: An empirical evaluation of the cognitive interview. *Journal of Police Science and Administration*, *12*(1), 74–80.

Han, S., & Dobbins, I. G. (2009). Regulating recognition decisions through incremental reinforcement learning. *Psychonomic Bulletin & Review*, *16*(3), 469–474.

Healy, A. F., & Kubovy, M. (1977). A comparison of recognition memory to numerical decision: How prior probabilities affect cutoff location. *Memory & Cognition, 5*(1), 3–9.

Hertzog, C., Dunlosky, J., & Robinson, A. E. (2007). Intellectual abilities and metacognitive beliefs influence spontaneous use of effective encoding strategies. Retrieved June 4, 2009, from Georgia Institute of Technology web site: http://www.psychology.gatech.edu/chertzog/papers/esm-15.pdf

Huang, I. (1986). Transitory Changes of Primacy and Recency in Successive Single-Trial Free Recall. *Journal of General Psychology*, *113*(1), 5–21.

Huang, I., Tomasini, J., & Nikl, L. (1977). The primacy and recency effects in successive single-trial immediate free recall. *Journal of General Psychology*, *97*(2), 157–165.

Jahnke, J. C. (1968). Delayed recall and the serial-position effect of short-term memory. *Journal of Experimental Psychology*, *76*(4, Pt. 1), 618–622.

Kang, S. H. K. (2009). The Influence of Test Expectancy, Test Format, and Test Experience on Study Strategy Selection and Long-term Retention. Unpublished doctoral dissertation, Washington University at St. Louis.

Klein, K. A., Addis, K. M., & Kahana, M. J. (2005). A comparative analysis of serial and free recall. *Memory & Cognition*, *33*(5), 833–839.

Kobasigawa, A., & Metcalf-Haggert, A. (1993). Spontaneous allocation of study-time by first- and third- grade children on a simple memory task. *The Journal of Genetic Psychology*, *154*, 223–235.

Koedinger, K. R., Aleven, V., Roll, I., & Baker, R. S. Jd. (2009). In vivo experiments on whether supporting metacognition in intelligent tutoring systems yields robust learning.In D. J. Hacker, J. Dunlosky & A. C. Graesser (Eds.), *Handbook of metacognition in education*. London: Routledge.

Konopka, A. E., & Benjamin, A. S. (2009). Schematic knowledge changes what judgments of learning predict in a source memory task. *Memory & Cognition*, *37*(1), 42–51.

Koriat, A., & Goldsmith, M. (1996). Monitoring and control processes in the strategic regulation of memory accuracy. *Psychological Review*, *103*, 490–517.

Koriat, A., Ma'ayan, H., & Nussinson, R. (2006). The intricate relationships between monitoring and control in metacogntion: Lessons for the cause-and-effect relation between subjective experience and behavior. *Journal of Experimental Psychology: General*, *135*(1), 36–69.

Kornell, N., & Bjork, R. A. (2007). The promise and perils of self-regulated study. *Psychonomic Bulletin & Review*, *14*, 219–224.

Kornell, N., & Bjork, R. A. (2008). Optimizing self-regulated study: The benefits-and costs-of dropping flashcards. *Memory*, *16*, 125–136.

Kornell, N., & Metcalfe, J. (2006). Study efficacy and the region of proximal learning framework. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *32*, 609–622.

Kornell, N., & Son, L. K. (2009). Learners' choices and beliefs about self-testing. *Memory*, *17*(5), 493–501.

Lajoie, S. P. (Ed.). (2000). Computers as cognitive tools (vol. 2): No more walls. Mahwah, NJ: Erlbaum.

Landauer, T. K., & Bjork, R. A. (1978). Optimum rehearsal patterns and name learning. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory* (pp. 625–632). London: Academic Press.

Le Ny, J. F., Denheire, G., & Taillanter, D. (1972). Regulation of study-time and interstimulus similarity in self-paced learning conditions. *Acta Psychologica*, *36*, 280–289.

Linn, M. C., Davis, E. A., & Bell, P. (Eds.). (2004). Internet Environments for Science Education. Mahwah, NJ: Lawrence Erlbaum Associates.

Liu, X., Finley, J. R., & Benjamin, A. S. (2009). Learning to avoid part-list cues. Manuscript in preparation.

Liu, X., & Fang, G. (2005). Development of children's strategy on allocation of study time. *Acta Psychologica Sinica*, *37*(5), 623–631.

Liu, X., & Fang, G. (2006). Development of elementary school students on allocation of study time under different time limit. *Acta Psychologica Sinica*, *38*(3), 365–374.

Lovelace, E. A. (1984). Metamemory: Monitoring future recallability during study. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*(4), 756–766.

Maki, R. H., & Serra, M. (1992). The basis of test predictions for text material. *The Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 116–126.

McDaniel, M. A., Blischak, D. M., & Challis, B. (1994). The effects of test expectancy on processing and memory of prose. *Contemporary Educational Psychology, 19*(2), 230–248.

Metcalfe, J. (2002). Is study time allocated selectively to a region of proximal learning? *Journal of Experimental Psychology: General*, *131*, 349–363.

Metcalfe, J., & Kornell, N. (2005). A region of proximal learning model of study time allocation. *Journal of Memory and Language*, *52*, 463–477.

Metcalfe, J., Schwartz, B. L., & Joaquim, S. G. (1993). The cue familiarity heuristic in metacognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 851–861.

Morris, C. D., Bransford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning & Verbal Behavior*, *16*(5), 519–533.

Murdock, B. B. (1962). The serial position effect of free recall. *Journal of Experimental Psychology*, *64*, 482–488.

Neely, J. H., & Balota, D. A. (1981). Test-expectancy and semantic-organization effects in recall and recognition. *Memory & cognition*, *9*(3), 283–300.

Nelson, T. O., & Dunlosky, J. (1991). When people's judgments of learning (JOLs) are extremely accurate at predicting subsequent recall: The "delayed-JOL effect". *Psychological Science*, *2*(4), 267–270.

Nelson, T. O., Dunlosky, J., Graf, A., & Narens, L. (1994). Utilization of metacognitive judgments in the allocation of study during multitrial learning. *Psychological Science*, *5*, 207–213.

Nelson, T. O., & Leonesio, R. J. (1988). Allocation of self-paced study time and the "labor-in-vain effect". *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*, 676–686.

Nelson, T. O., & Narens, L. (1990). Metamemory: A theoretical framework and new findings. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 26, pp. 125–141). New York: Academic Press.

Nelson, T. O., & Narens, L. (1994). Why investigate metacognition? In J. Metcalfe, & A. P. Shimamura (Eds.), *Metacognition: Knowing about knowing* (pp. 1–25). Cambridge, MA: The MIT Press.

Nickerson, R. S. (1984). Retrieval inhibition from part-set cuing: A persisting enigma in memory research. *Memory & cognition*, *12*(6), 531–552.

Postma, A. (1999). The influence of decision criteria upon remembering and knowing in recognition memory. *Acta Psychologica*, *103*(1–2), 65–76.

Postman, L. (1964). Studies of learning to learn: II. Changes in transfer as a function of practice. *Journal of Verbal Learning & Verbal Behavior*, *3*(5), 437–447.

Reder, L. M. (1987). Strategy selection in question answering. *Cognitive Psychology*, *19*, 90–138.

Rhodes, M. G., & Castel, A. D. (2008). Metacognition and part-set cuing: Can interference be predicted at retrieval? *Memory & Cognition*, *36*, 1429–1438.

Ritter, S., Anderson, J. R., Koedinger, K. R., & Corbett, A. (2007). Cognitive tutor: Applied research in mathematics education. *Psychonomic Bulletin & Review*, *14*(2), 249–255.

Roediger, H. L., III. (1980). The effectiveness of four mnemonics in ordering recall. *Journal of Experimental Psychology: Human Learning & Memory*, *6*(5), 558–567.

Roll, I., Aleven, V., McLaren, B. M., & Koedinger, K. R. (2007). Can help seeking be tutored? Searching for the secret sauce of metacognitive tutoring. In R. Luckin, K. Koedinger, & J. Greer (Eds.), *Proceedings of the 13th International Conference on Artificial Intelligence in Education, AIED 2007* (pp. 203–210). Amsterdam, the Netherlands: IOS Press.

Rotello, C. M., & Macmillan, N. A. (2008). Response bias in recognition memory. In A. S. Benjamin & B. H. Ross (Eds.), *The Psychology of Learning and Motivation: Skill and Strategy in Memory Use* (Vol. 48, pp. 61–94). London: Academic Press.

Schwartz, B. L., & Metcalfe, J. (1994). Methodological problems and pitfalls in the study of human metacognition. In J. Metcalfe & A. Shimamura (Eds.), *Metacognition: Knowing about knowing* (pp. 93–114). Cambridge, MA: MIT Press.

Serra, M. J., & Metcalfe, J. (2009). Effective implementation of metacognition. In D. Hacker, J. Dunlosky, & A. Graesser (Eds.), *Handbook of Metacognition and Education* (pp. 278-298). New York, NY: Routledge.

Simon, H. A. (1957). *Models of man: Social and rational*. New York: Wiley.

Slamecka, N. J., & Graf, P. (1978). The generation effect: Delineation of a phenomenon. *Journal of Experimental Psychology: Human Learning & Memory*, *4*, 592–604.

Smith, S. M. (1979). Remembering in and out of context. *Journal of Experimental Psychology: Human Learning and Memory*, *5*(5), 460–471.

Son, L. K. (2004). Spacing one's study: Evidence for a metacognitive control strategy. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*, 601–604.

Son, L. K., & Metcalfe, J. (2000). Metacognitive and control strategies in study-time allocation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 204–221.

Son, L. K., & Sethi, R. (2006). Metacognitive control and optimal learning. *Cognitive Science*, *30*, 759–774.

Stretch, V., & Wixted, J. T. (1998). On the difference between strength-based and frequency-based mirror effects in recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 1379–1396.

Surber, J. R. (1983). The influence of decision factors on what is reported in free recall of a brief narrative. *Contemporary Educational Psychology*, *8*(2), 119–126.

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.
Thiede, K. W., & Dunlosky, J. (1999). Toward a general model of self-regulated study: Analysis of selection of items for study and self-paced study time. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 4*, 1024–1037.
Toppino, T. C., Cohen, M. S., Davis, M. L., & Moors, A. C. (2009). Metacognitive control over the distribution of practice: When is spacing preferred? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(5), 1352–1358.
Tullis, J. G., & Benjamin, A. S. (2009). The effectiveness of self-paced study. Manuscript submitted for publication.
Waugh, N. C. (1961). Free versus serial recall. *Journal of Experimental Psychology*, *62*(5), 496–502.
Williams, M. D., & Hollan, J. D. (1981). The process of retrieval from very long term memory. *Cognitive Science*, *5*(2), 87–119.
Winne, P. H., & Nesbit, J. C. (2009). Supporting self-regulated learning with cognitive tools. In D. J. Hacker, J. Dunlosky & A. C. Graesser (Eds.), *Handbook of metacognition in education*. London: Routledge.
Wolf, G. (2008, May). Want to remember everything you'll ever learn? Surrender to this algorithm. *Wired*, *16*.
Wozniak, P. A., & Gorzelañczyk, E. J. (1994). Optimization of repetition spacing in the practice of learning. *Acta Neurobiologiae Experimentalis*, *54*, 59–62.
Zacks, R. T. (1969). Invariance of total learning time under different conditions of practice. *Journal of Experimental Psychology, 32*, 441–447.