Forgetting as a Friend of Learning

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It is natural to think that learning is a matter of building up skills or knowledge in one's memory and that forgetting is a matter of losing some of what was built up. From that perspective, learning is a good thing and forgetting is a bad thing. The relationship between learning and forgetting is not, however, so simple, and in certain important respects is quite the opposite: Conditions that produce forgetting often enable additional learning, and learning or recalling some things can contribute to forgetting other things. In this chapter I focus on why forgetting enables, rather than undoes, learning.

Among his multitude of contributions to research on human learning and memory, Larry Jacoby was among the first to emphasize that forgetting can facilitate learning. In an important early paper (Jacoby, 1978; also see Cuddy & Jacoby, 1982), Larry characterized restudying after *not* forgetting as "remembering the solution" and restudying after forgetting as "solving a problem"—that is, again carrying out activities that have the potential to enhance subsequent retention. I discuss Larry's arguments and results later in this chapter.

My own interest in the relationship between forgetting and learning goes back to my graduate-student days at Stanford University, during the heyday of fitting learning and memory data with multi-state Markov models. David Rumelhart and I (Bjork, 1966; Rumelhart, 1967) got caught up in the challenge of trying to account for the trial-by-trial short-term-memory and long-term-learning effects of any arbitrary spacing of successive inter-trial intervals during paired associate learning. The idea behind what became my dissertation was to do away with the usual constraint that a given pair in a to-be-learned list of paired associates does not come up again until the next cycle through the list—a constraint that makes short and long intervals between successive presentations of a given item very infrequent. Instead, I let each successive interval for a given pair be determined randomly from a uniform distribution of intervals, which led to highly variable inter-presentation sequences, such as the examples shown in Figure 1, where the proportion of correct responding and the latency of responding are shown as a function of trial number and the spacing between successive trials.

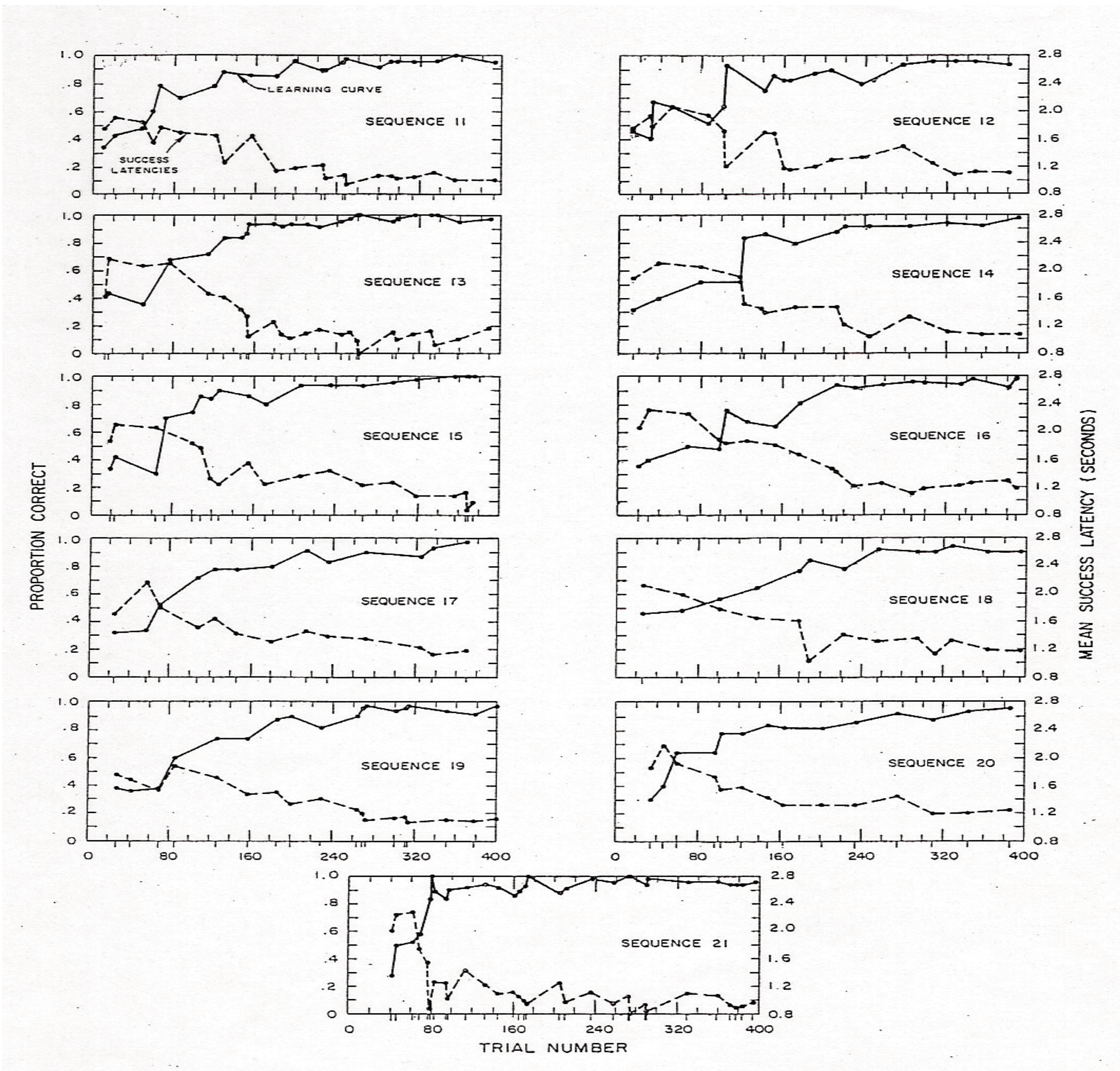

Figure 1. Learning curves and response-time curves as a function of 11 of the 21 different sequences of successive inter-presentation intervals used by Bjork (1966). In contrast to the way that learning curves are typically plotted, successive trials are spaced on the abscissa in accord with the actual spacing between successive trials for a given sequence. The curves illustrate how much performance can vary as a function of successive intervals, a variation that is averaged away when learning curves are plotted in the typical fashion.

I was able to account in some detail for both the short-term and long-term effects of arbitrary sequences of inter-presentation intervals with a Markov model that assumed that a given pair could be in one of four states of knowledge: an initial unlearned state, a short-term memory state, a forgotten state, and a (permanently) learned state. Of relevance to the present chapter—and shocking at the time—the best fitting estimate of the probability of transitioning to the learned state if an item was still in the short-term memory state from the prior trial, and had not been learned already, was exactly zero. Thus, for learning to happen, the item needed to be forgotten from short-term memory prior to its next presentation.

In the years that followed, my students, collaborators, and I found other instances where forgetting enabled learning, usually in the context of exploring some other issue. Ted Allen and I, for example, in an experiment designed to discriminate between alternative explanations of the spacing effect (that long-term recall is enhanced by spacing, rather than massing, repeated study sessions), found that a more difficult intervening activity could both produce more forgetting and enhance learning (Bjork & Allen, 1970). On each trial, participants studied a set of three words and then had to carry out an easy or difficult intervening task (shadowing aloud 3-digit or 5-digit numbers every 1.5 seconds, respectively). On an unpredictable half of the trials they were asked to recall the set of words, whereas on the other trials they were presented the words again to restudy, after which there was a longer period of medium-difficulty shadowing (4-digit numbers every 1.5 second) before they were cued to recall the to-be-remembered words.

We found, not surprisingly, that the more difficult intervening task caused more forgetting: 45 percent of the word trigrams were recalled correctly after 12 seconds of the easy task, whereas only 32 percent of the trigrams were recalled correctly after the difficult task. When the trigrams were presented again for restudy, however, rather than tested, and then tested after 30 seconds of the medium difficulty shadowing task, the relationship reversed: 70 percent of the trigrams were recalled correctly when the interval between presentations was filled with the easy task, whereas 77 percent of the trigrams were recalled correctly when the interval was filled with the more difficult task. Thus, the more difficult task produced more forgetting, but enhanced learning. With respect to the main motivation for the study, the findings also argued against a consolidation interpretation of spacing effects (why should there be more consolidation of the first presentation during a difficult, versus easy, subsequent activity?).

Not long thereafter, Steve Smith, Arthur Glenberg, and I found that changing the environmental context from study to test could also produce forgetting, but enhance learning. When materials were studied in one room on the University of Michigan campus and then, 3 hours later, either tested in that room or a very different room, we found that changing the context from study to test impaired recall. If, though, the materials were restudied, rather than tested, we then found that the change in context enhanced later recall, as measured by recall in a neutral room 3 hours after the second study session.

Beyond the evidence that a more difficult intervening activity, or a change of environmental context, can both produce forgetting and enhance learning, there is, of course, the spacing effect, itself. That is, there is 130 years or so of evidence that lengthening the interval from a first study opportunity to a test or second study opportunity can both increase forgetting, but enhance learning. Melton (1967), for example, described the spacing effect as paradoxical—because it suggested that forgetting can help memory.

Conjectures as to Why Forgetting Enables Learning

In the theoretical framework that Elizabeth Bjork and I refer to as “a new theory of disuse” (Bjork & Bjork, 1992), a framework that has guided much of our recent research, the fact that inducing forgetting can enhance learning is explained in terms the theory's distinction between *storage strength* versus *retrieval strength*. The retrieval strength of an item in one's memory reflects its current ease of access—that is, how primed or activated it is in the context of current cues—whereas the storage strength of that item reflects how interassociated or "entrenched" it is with everything else in one's memory. Current retrieval strength is assumed to determine completely the probability that an item can be recalled, whereas storage strength acts as a latent variable that retards the loss or enhances the gain of retrieval strength. Thus, many items in memory, as an old friend's name, a street address we once had, or our high-school French, can be strongly registered in memory in the storage-strength sense, but be non-recallable because their retrieval strength, via disuse, has become too low to support recall.

The distinction between storage strength and retrieval strength corresponds, in a general way, to the time-honored distinction between learning and performance (for a recent discussion of the learning-versus-performance distinction in the domains of cognitive/motor skills and verbal/conceptual learning, see Soderstrom & Bjork, 2013). What we can observe and measure is performance, which, in the theory, reflects retrieval strength; what we must infer is learning, which, in the theory, reflects storage strength. Conceptually, the distinction is similar to Estes' (1955) distinction between *habit strength* and *response strength,* to Melton's (1963) distinction between *trace storage* and *trace utilization*, and to Tulving and Pearlstone's (1966) distinction between *availability* and *accessibility*.

Within the new-theory-of-disuse framework, the key to why forgetting can enable learning is the assumption that increments in storage strength are assumed to be a decreasing function of current retrieval strength. That is, the more accessible an item in the retrieval-strength sense, the smaller the increments (learning) caused by re-study in the storage-strength sense. Thus, as shown in Figure 2, there is an asymmetry in terms of the interaction of storage strength and retrieval strength: Increments in retrieval strength due to re-study are larger the higher the current storage strength, but increments in storage strength due to re-study are smaller the higher the current retrieval strength.

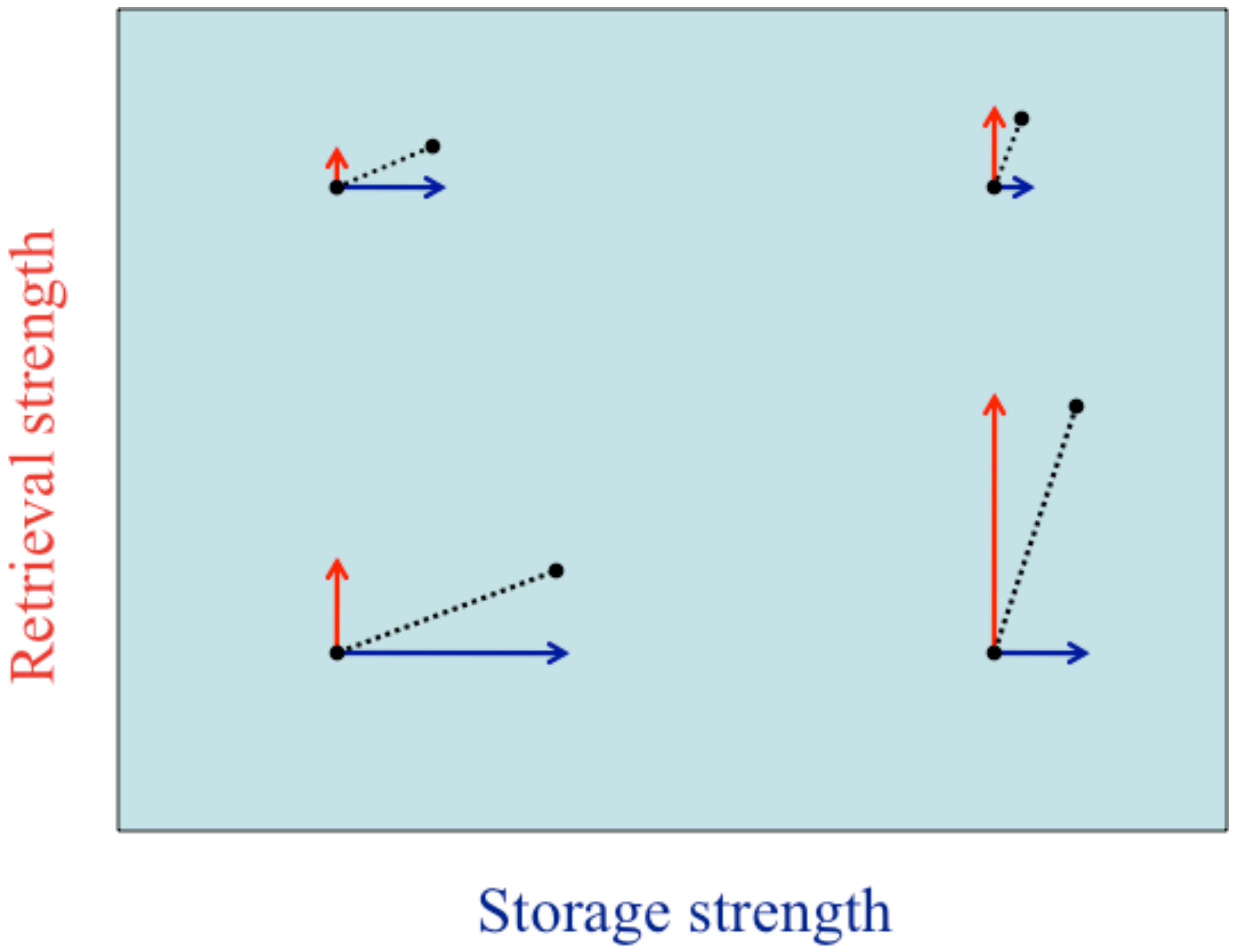

Figure 2. Illustration of the effects of a study trial assumed by the new theory of disuse (Bjork & Bjork, 1992). Gains in retrieval strength are an increasing function of current storage strength, whereas gains in storage strength are a decreasing function of current retrieval strength.

The new theory of disuse is not a process model. A number of mechanisms could underlie *why* increments in storage strength are a decreasing function of current retrieval strength. The leading contenders are summarized below.

Encoding Variability

As McGeoch (1932) might have been the first to emphasize, one contributor to forgetting is “altered stimulating conditions” (p. 365). That is, as a retention interval increases, so does—typically—the discrepancy between the stimulus cues present at the time of test versus those that were present at the time of study. Contextual cues, however, influence not only what is retrievable from memory, but also how information is encoded, so when to-be-learned information is re-presented, rather than tested, the altered cues provide opportunities for encoding that differ from, or add to, the original encoding. That is, context change induces forgetting, but also can enhance learning via the to-be-remembered information becoming associated with a greater range of contextual cues. Such increased encoding variability helps to sustain access to that information, especially at a delay and as contextual cues change.

Estes (1955) formalized such a mechanism in his stimulus-fluctuation model, originally proposed to account for forgetting and spontaneous-recovery phenomena in animal learning. The model assumes that the animal samples from among the stimulus “elements” available at the time of a test trial and that the proportion of cues already associated to some target response determines the likelihood the response is executed. Forgetting occurs in the model because the stimulus elements in the situation are assumed to fluctuate between being “available” for sampling and being “unavailable” for sampling, owing to changes in the animal’s orientation, body state, and so forth. Elements conditioned to some target response can be replaced by unconditioned elements owing to such fluctuation, which decreases the probability of responding with the target response. Such “replacements,” however, also make new elements available for conditioning—that is, can enhance learning by increasing the total number of elements conditioned to the target response, which is what will determine performance in the long term. From a formal standpoint, the proportion of conditioned elements in the currently available cues corresponds to retrieval strength in the new theory of disuse and the proportion of conditioned elements in total populations of elements corresponds, roughly, to storage strength.

As already mentioned, Estes formulated the fluctuation model to account for various forgetting, spacing, and spontaneous-recovery findings in the animal-learning literature. Gordon Bower (1972) extended and elaborated the model to account for a range of human-learning phenomena, and the basic fluctuation mechanism has been incorporated into more recent quantitative models (e.g., Glenberg, 1979; Mensink & Raiijimakers, 1988).

Retrieval—and/or Reminding—as a Learning Event

A basic fact about human memory is that retrieving information from long-term memory is fallible and probabilistic. Another basic fact is that the act of retrieval is a learning event—or "memory modifier" (Bjork, 1975)—in the sense that the retrieved information becomes more recallable in the future than it would have otherwise. In fact, retrieval is a powerful learning event, one that is substantially more powerful than is restudying (for a review of "test effects," see Roediger & Karpicke, 2006b).

Importantly, for present purposes, the more difficult or involved the act of retrieval the more it facilitates subsequent retrieval (e.g., Whitten & Bjork, 1977). Thus, retrieval of procedures and skills from memory can be viewed as a kind of skill—one that, like other skills, profits from practice—and retrieval events during learning that are more difficult or involved, owing to forgetting (loss of retrieval strength) during the learning process itself, constitute better practice for later efforts to retrieve (Bjork, 1988; Thios & D'Agostino, 1976). That is, as events pass and cues change across intervals during the acquisition of process, retrieval of what has been studied or practiced earlier during the acquisition process becomes more difficult, but also more like the retrieval processes required on the post-acquisition final test. From that perspective, embedded tests during the acquisition process constitute better practice for the final test than do restudy opportunities, which helps to explain why testing, even without feedback, can produce better post-acquisition performance than does restudying, especially after a long retention interval.

Restudying does, though, enhance later recall and—in the case of restudying—the argument is that the re-representation of the to-be-learned material triggers “reminding,” that is, recollecting—or reconstructing—the initial study episode (for discussions of the broader roles of reminding, see Benjamin & Ross, 2011; Benjamin & Tullis, 2010; and Hintzman, 2010, 2011). Again, the more difficult or involved such reminding is, provided it succeeds, the larger at the benefits, so forgetting, up to a point, enhances the benefits of reminding (e.g., Appleton-Knapp, Bjork, & Wickens, 2005; Cuddy & Jacoby, 1982), as measured by later recall.

Solving a Problem versus Remembering the Solution

Jacoby (1978) argued that fluent remembering of a prior presentation of some to-be-learned material results in the learner bypassing processing activities that would otherwise be required, activities of the type that enhance later recall. To illustrate, he used the following example (p. 649):

> “Suppose that you are asked to find the sum of 37 + 15 + 12. After having obtained this sum you are immediately presented with the same problem. The type of processing that you do will differ drastically on the repeated presentation. On the first encounter you undoubtedly went through the process of addition to obtain the sum; on the second encounter, the sum is readily available and can be given without going back through the operation of adding the numbers. Indeed, a full repetition of the processing activities may be difficult, if not impossible, without some delay.

Jacoby goes on to argue that the effects of spacing repetitions of to-be-learned materials can act in a similar fashion. Memorizing a list of words or paired associates can be thought of as confronting a series of problems: The learner must find processing activities that will make a given item recallable on a final test, such as creating an image of the referent of a to-be-recalled word. In the case of a repeated presentation of a to-be-remembered word, however, it will be difficult or impossible to carry out additional productive processing if the processing of the initial presentation remains easily accessible. That is, "remembering the solution" will impede "[re]solving the problem."

Jacoby (1978) and Cuddy and Jacoby (1982) went on to demonstrate in various ways that reducing the accessibility of the prior processing of a to-be-learned item—that is, inducing forgetting—enhanced the effectiveness of restudying the item, as measured by later recall. The results of Jacoby's (1978) Experiment 1, shown in Figure 4, provide a particularly dramatic example of how ineffective "remembering the solution" can be for later recall. Participants had to learn paired associates that were either presented intact (e.g., FOOT: SHOE) or were presented with the cue word intact but with letters missing from the response word (e.g., FOOT: S**E), meaning that the response word had to be "constructed" from the cue word and letter cues. After the study phase there was then a final cued-recall test (e.g., FOOT: __?__) for the studied pairs.

As shown in Figure 4, when a given pair was presented only once, either in the "read" condition or the "construct" condition, final cued-recall test exhibited a very large generation benefit: The "construct" condition led to about twice the level of recall of the "read" condition. What is most striking though, is the pattern of findings for the pairs that were presented twice, either in a Read-Read condition (FOOT: SHOE; FOOT: SHOE) or in a Read-Construct condition (FOOT: SHOE; FOOT: S**E), and with either zero or twenty intervening trials on other pairs. With zero intervening pairs the Read-Construct condition, rather than combining the benefits of reading and constructing, resulted in a level of cued-recall performance that was much lower than the level produced by a single construct trial. That is, when participants could simply remember the solution from the preceding trial, the benefits of constructing were minimal. When 20 trials—and, presumably, substantial forgetting—intervened between the initial study trial and the later construct trial, however, the construct again required "solving the problem," which increased later recall substantially.

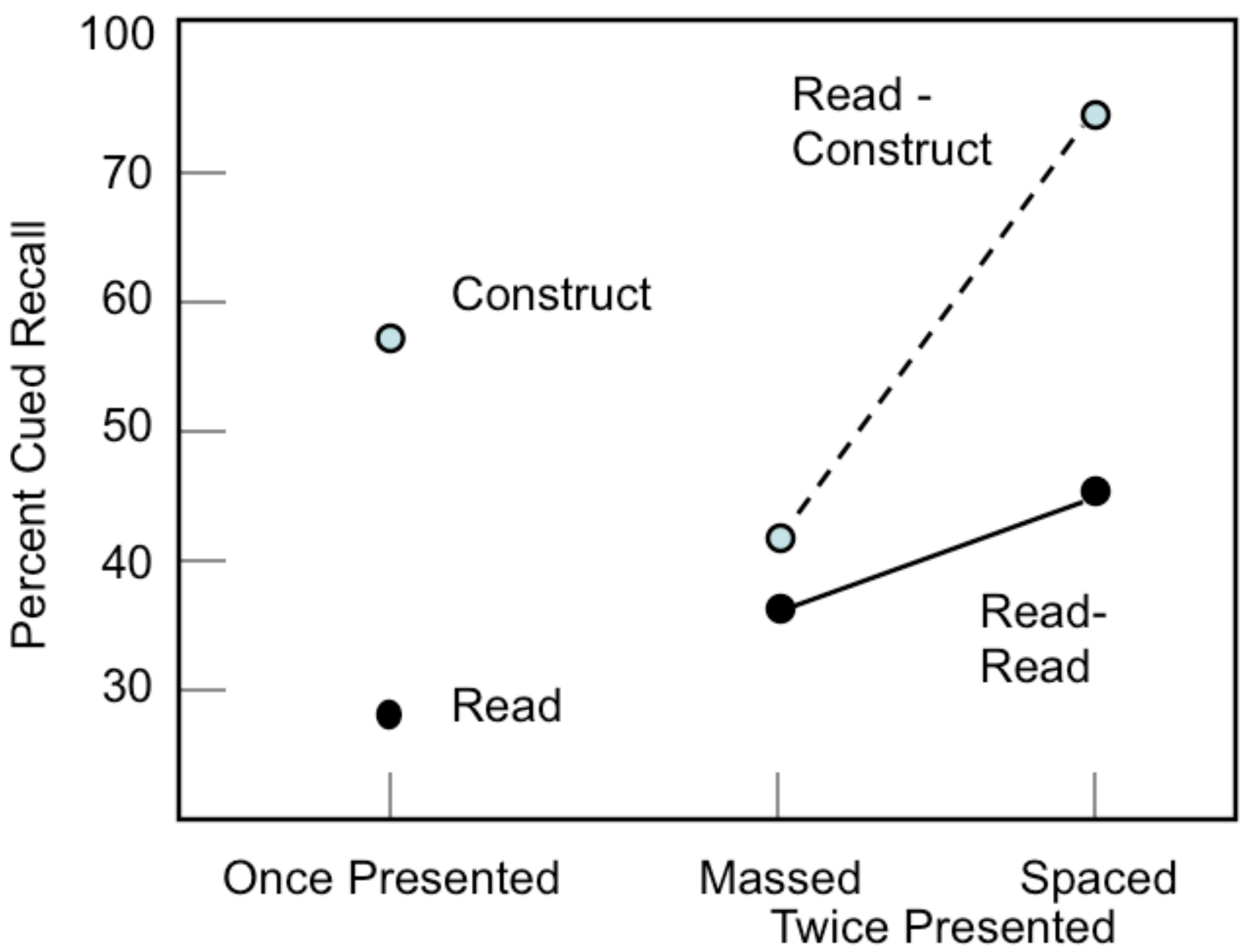

Figure 3. Percent final cued recall of paired associates as a function of whether they were presented once, twice massed, or twice spaced. On "Read" trials pairs were present intact (e.g., FOOT: SHOE), whereas on "Construct" trials the response word had to be constructed (e.g., FOOT: S**E). Adapted from Jacoby (1978, Figure 1).

Encoding the Gist, Rather than the Details

In the context of inductive learning—that is, the learning of categories and concepts from examples—there is another conjecture as to why forgetting can enable learning. Beginning with a study by Kornell and Bjork (2008), in which participants learned the styles of painters from examples of their paintings, there have now been a number of demonstrations that inductive learning, as measured by the ability to classify new examples, profits from interleaving and/or spacing the examples of different categories(e.g., Birnbaum, Kornell, Bjork, & Bjork, 2013; Kang & Pashler, 2012; Kornell, Castel, Eich, & Bjork, 2010; Vlach, Kornell, & Sandhofer, 2008; Wahlheim, Dunlosky, & Jacoby, 2011). These findings have stirred considerable interest, not only because it would seem, a-priori, that blocking or massing the examples of a given category would make the commonalities across examples that define the category maximally apparent, but also because participants believe that blocking, not interleaving, facilitates learning (even after their final-test performance has demonstrated the opposite).

When and why interleaving enhances inductive learning remains an active issue, but Vlach et al. (2008) proposed that spacing between successive exemplars of a given category induces forgetting and that forgetting promotes abstraction. The basic idea is that massing can lead to the encoding of details shared by successive exemplars of a given category that then turn out not to be diagnostic of that category, versus other categories, whereas when events intervene between successive exemplars of a given category what will tend to again be activated are the central features or gist of the category. Such more abstract encodings are then also more likely to be durable and support performance when new exemplars need to be categorized on the final test.

Forgetting, Desirable Difficulties, and the Potential for Learners to Be Fooled

As I mentioned at the outset, the very notion that forgetting might help learning is unintuitive, which can lead us to assume that conditions of learning that prevent forgetting are to be preferred. Our judgments as to how we should optimize our own or others' learning can also be misled, however, by our subjective experiences and objective performance during the learning process. Conditions of instruction that appear to create difficulties for the learner, causing forgetting during the acquisition process and slowing the rate of *apparent* learning (as measured by current performance), can optimize long-term retention and transfer, whereas conditions of instruction that make performance improve rapidly can fail to support long-term retention and transfer. To the extent, therefore, that we consider current performance (retrieval strength) to be a reliable index of learning (storage strength) we become prone to choosing poorer conditions of instruction or practice over better conditions. Also, as Larry Jacoby was among the first to emphasize (see, e.g., Jacoby, Kelley, & Bjork, 1994), conditions that make performance improve rapidly are often conditions that also create a subjective sense of ease or fluency, which can contribute to our preference for such conditions.

That we are indeed prone to interpreting our current performance and/or subjective sense of fluency as evidence of learning and comprehension has been documented in multiple studies involving what I have termed "desirable difficulties" (Bjork, 1994a, 1994b), but which learners tend not to desire (see, e.g., Baddeley & Longman, 1978; Benjamin, Bjork, & Schwartz, 1998; Cohen, Yan, Halamish, & Bjork, in press; Heulser & Metcalfe, 2012; Koriat & Bjork, 2005; Kornell & Bjork, 2008; Reder, 1987; Roediger & Karpicke, 2006a; Simon & Bjork, 2001; and Tauber, Dunlosky, Wahlheim, & Jacoby, 2013). Examples of manipulations that induce "desirable difficulties" include varying the conditions of instruction or practice versus keeping them constant and predictable; distributing, rather than massing, repeated study opportunities; providing intermittent, rather than continuous, feedback to learners; using tests, rather than presentations, as learning events; and interleaving, rather than blocking, separate to-be-learned tasks.

It needs to be stressed that the word "desirable" is important. As Elizabeth Bjork and I have emphasized elsewhere (E. L. Bjork & R. A. Bjork, 2011; Bjork, 2011), such difficulties are desirable not because they create difficulties per se, but because responding to such manipulations—successfully—engages the very encoding and retrieval processes that support long-term recall and transfer. If a given learner is not equipped—by virtue of his or her prior learning, for example—to overcome a given difficulty, that difficulty becomes an undesirable difficulty. If a level of variation and/or spacing between successive learning trials is introduced that makes reminding fail, for example, such variation and/or spacing creates an undesirable difficulty (see, e.g., Appleton-Knapp et al., 2005). Jacoby's (1978) experiment discussed earlier (see Figure 3) provides another possible example. The need to generate "shoe" when presented FOOT: S**E created a desirable difficulty for Jacoby's participants, but that finding was contingent on the generation succeeding; had the participants not know the English language, such "construct" trials would have created an undesirable difficulty.

With respect to when difficulties are and are not desirable, it is important to emphasize that my definition of forgetting in the present chapter differs from the all-or-none way forgetting is often characterized—namely, that if some information or procedure can still be recalled, it has not been forgotten, whereas if that information or procedure cannot be recalled, it has been forgotten. Instead, I am defining forgetting as a decrease in accessibility (retrieval strength)—that is, a decrease in how readily accessible some information or procedure is at a given point in time and in the presence of current cues. Thus, for example, some information or procedure may remain recallable, if with greater difficulty, at a delay, even though its retrieval strength has decreased. Similarly, in the retrieval-strength sense, forgetting can continue past the point that some information or procedure becomes non-recallable. That is, some information or procedure that does not have a current level of retrieval strength sufficient to support its being successfully retrieved can still be forgotten further, so to speak, across an additional delay and intervening events as its retrieval strength continues to decrease.

Concluding Comments on the Importance of Forgetting

In a recent chapter (Bjork, 2011), I argued that the human memory system is characterized by a unique symbiosis of learning, remembering, and forgetting. *Forgetting*, rather than undoing learning, enables learning and focuses remembering; *Remembering* creates learning and produces forgetting; and *Learning* begets remembering, contributes to forgetting, and enables new learning. Among the definitions of symbiosis is "a relationship of mutual benefit or dependence" (American Heritage Dictionary, 2006). The relationships among remembering, forgetting, and learning are indeed symbiotic, but also complex and unintuitive. It is a system that is remarkably interesting and effective, if fallible, and is no less remarkable by virtue of being so frequently underappreciated and misunderstood by the user.

In this chapter I have focused on forgetting as an enabler of learning, but forgetting plays other crucial roles as well. Forgetting of out-of-date information and procedures is essential with respect to keeping our memories current, for example, and forgetting "focuses remembering" in the sense that accessing current information or procedures can produce retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994) of competing information or procedures. Storm (2011) has emphasized, too, that such retrieval-induced forgetting also plays a role in any act of thinking and problem solving where it is necessary to "overcome the fixating consequences of interfering information" (p. 295).

Forgetting, its adaptive roles notwithstanding, is not, of course always desirable or adaptive, and one goal of this Festschrift is to induce remembering, not forgetting. As this volume documents, we are indebted to the unforgettable Larry L. Jacoby for his multifaceted and enduring contributions not only to our understanding of how and why we, as humans, remember or fail to remember, but also when and why we are subject to illusions of comprehension, competence, and remembering.

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