Forgetting as the Friend of Learning:

Implications for Teaching and Self-regulated Learning

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Abstract. One of the "important peculiarities" of human learning (4) is that certain conditions that produce forgetting—that is, impair access to some to-be-learned information studied earlier—also enhance the learning of that information when it is restudied. Such conditions include changing the environmental context from when some to-be-learned material is studied to when that material is restudied; increasing the delay from when something is studied to when it is tested or restudied;, and interleaving, rather than blocking, the study or practice of the components of to-be-learned knowledge or skills. In this paper, we provide some conjectures as to why conditions that produce forgetting can also enable learning and why a misunderstanding of this peculiarity of how humans learn can result in non-optimal teaching and self-regulated learning.

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It is natural to think that learning consists of building up knowledge or skills in our memories and that forgetting is losing some of what was built up. The relationship between learning and forgetting, however, is not so simple and is, in some respects, quite the opposite. One of the "important peculiarities" (4) of human learning is that certain conditions that produce forgetting—that is, decrease our ability to access what we have stored in our memories—actually create opportunities to enhance our level of learning.

In what follows, we first provide examples of manipulations of the conditions of learning that induce forgetting but then enhance learning when the to-be-learned material or skill is restudied or re-practiced. We then provide several conjectures as why conditions that induce forgetting can enable learning, and we conclude with some comments on why learners are prone to being misled as to what are, and are not, effective ways to learn.

Examples of conditions that induce forgetting, but enhance learning

Varying environmental contexts. One example of a manipulation that produces forgetting, but enhances learning, is changing the environmental context from where material is initially studied to where that material is tested or restudied. When something is initially studied in a particular environmental location and then tested at a later time, there tends to be a "context effect"—namely, that the material studied is more recallable when tested in the same context where it was studied than when tested in a different environmental context. If, however, rather than being tested, the material is restudied, either in the same location or a different location, and recall is then tested in some new setting at a later time, the pattern is very different: Having restudied the material in a different location where more of it will have been forgotten at the time of this restudy, rather than the original location where more of it will still be accessible at the time of this restudy, actually enhances later recall of that material (see, e.g., 15)

The fact that studying some to-be-learned information in two different locations, rather than in the same location both times, is interesting and important for a number of reasons. One reason is that such findings run counter to the advice students are often given—namely—to find a good place to study (on a college campus, say) and then do all of one's studying in that place. It is possible that such advice is good advice if one's problem as a student is to get one's self to study, but it is not good advice if one's goal as a student is to be able, at a later time, to recall *what* one has studied.

Increasing the interval between study opportunities. Perhaps the ultimate example of a manipulation of the conditions of study or practice that produces forgetting, but enhances learning, is the "spacing effect." As we have all experienced when the recall of some studied material is tested after a delay, the longer the delay the poorer our ability to recall that material—that is, the more our forgetting. If, however, the material is restudied after a delay, rather than tested, increasing the delay between such study episodes has benefits, not costs, in terms of one's ability to recall the material at a later time—and substantial benefits. Such "spacing effects" have been demonstrated intermittently across the entire 133-year history of controlled research on human learning and with a great variety of to-be-learned materials (for reviews, see 5, 16).

As with the benefits of varying the environmental context when restudying, the benefits of spacing are often not appreciated by learners. In fact, students often think that it is optimal to restudy some to-be-learned material right away, such as re-reading a chapter in a textbook right away—perhaps with the idea of avoiding forgetting and/or getting a clearer idea of what was missed the first time through the chapter.

In addition, a student's own experiences can be misleading with respect to realizing the benefits of spacing for long-term learning because the benefits of spacing only become apparent after a delay. Repeatedly studying some material without any interpolated spacing—sometimes referred to as "massed practice"—can produce good performance on an immediate test, so "cramming" can yield good performance on a test administered immediately after the cramming. And, yes, staying up all night to cram for an exam given the next morning can sometimes yield good performance on that specific exam. Such good performance is misleading, however, because cramming is followed by dramatic forgetting. If the material needs to be remembered over the long term, and/or is a foundation for subsequent learning, cramming is a very bad idea.

Interleaving, rather than blocking, study or practice of to-be-learned materials or skills. Related to the benefits of spacing, interleaving the study or practice of the separate components of to-be-learned material or skills can induce forgetting, but enhance learning. Such benefits were first demonstrated in the context of learning motor skills, such as learning several different patterns of knocking over hinged barriers in a laboratory task (13), or learning three different types of serves in badminton (6), or learning to hit fastballs, change-ups, and curve balls in baseball (7). In such studies, blocking the practice trials on each of the to-be-learned skills produced better performance during practice, but then resulted in poorer learning, as measured by retention and/or execution of the skill after a delay following the practice phase, or by a later test of transfer—that is, performance on an altered version of the task.

Across more recent years, benefits of interleaving have also been demonstrated with verbal and conceptual tasks. Kornell and Bjork (9), for example, using a task that required participants to learn the styles of 12 different artists from examples of their paintings, found benefits of interleaving. Six paintings by each of the artists were shown blocked by artist, or interleaved among the paintings by other artists, and the participants were then asked to identify who, among the 12 artists, had painted each of a series of new paintings (i.e., paintings not seen during practice). In terms of participants' ability to identify which artist was responsible for each new painting, there was a sizable benefit of previous interleaving, even though the participants who experienced both blocking and interleaving felt strongly that blocking, not interleaving, enhanced their learning.

Benefits of interleaving have also been demonstrated by Rohrer and colleagues (e.g., 12) in the learning of mathematics, especially in algebra instruction—and in actual schools, as well as in laboratory experiments. The details of that body of research suggests that interleaving the types of to-be-learned problems during practice enhances students' ability on a later test to identify what type of procedure (such as using the Pythagorean Theorem) should be applied to solve a given problem.

Again, these findings suggest that standard practices of teaching are often not optimal. Teachers are susceptible to thinking that blocking instruction by problem type or domain helps students, whereas interleaving such instruction might cause confusion.

In addition, practice questions, such as those at the end of a textbook chapter or in a separate workbook are typically blocked by problem type. Such blocking can create an unreliable sense of understanding or comprehension and disappointing performance on a later, possibly important, test in which problems of the same type will typically not be together nor accompanied by a clue as to the procedure that should be used to solve a given problem. In fact, a critical component of doing well on important tests, such as end-of-year tests, is deciding what procedure is required to solve a given problem. Interleaved practice gives the student practice in making such decisions; blocked practice does not.

Conjectures as to Why Forgetting Enables Learning

From a theoretical standpoint, there are several reasons why conditions that induce forgetting—such as context change, spacing, and interleaving—can also enhance learning when the to-be-learned material is later restudied or the to-be-learned skill is later practiced. Those reasons include the following.

Context change induces encoding variability. Contextual cues influence not only what is retrievable from memory, but also how information is encoded in the first place. So while a change in environmental context can decrease the likelihood that information studied in a different context can now be recalled, it also increase the likelihood that when such information is restudied it will now become associated with a greater range of contextual cues. Thus, increased encoding variability can help to sustain access to the to-be-remembered information across a variety of different contexts, especially at a delay and as contextual cues change, which—in turn—can foster transfer of that learning to new situations.

Retrieval as a learning event. As we have all experienced, retrieving information from one's long-term memory is fallible and probabilistic. Such retrieval is, in fact, a kind of skill—one that, like other skills, profits from practice. In addition, research has shown (e.g., 2) that retrieval events during the learning process that are more difficult or involved, owing to forgetting during the learning process itself, constitute better practice for one's later efforts to retrieve. That is, the more difficult or involved the act of retrieval at an earlier time, the more that act exercises the processes that will be needed for successful retrieval at a later time. To the degree, therefore, that spacing or a change of contextual cues can make the retrieval of information studied earlier more involved and difficult, such spacing and contextual variation will also make the act of retrieval (provided it succeeds) more potent in fostering the subsequent retrieval of that information.

Solving a problem versus remembering the solution. A final conjecture as to why forgetting can enhance learning, put forward by Jacoby (8), is that effective learning can be viewed as a kind of problem solving task: Learners need to find operations and activities that will make the to-be-learned material recallable after a delay. In that view, forgetting across repetitions of to-be-learned materials is necessary for the learner to be able to carry out again the types of productive activities that enhance long-term recall. An example from one of Jacoby's experiments—one in which the participants had to learn a number of associated word pairs, such as "Foot: Shoe," and then in a later test had to try to recall "Shoe" when shown "Foot: ???" as a cue—might help to clarify the idea. When participants were first shown a pair such as "Foot: Shoe" to study and then later were presented another study trial in which they had to generate "Shoe" when shown “Foot: S**e” as a cue, it mattered a great deal how many other pairs had been presented for study before the participants had to generate “Shoe” to that cue. When there was essentially no delay after having seen the solution, so to speak, there was also no benefit of generating “Shoe” to the cue “Foot: S**e” in terms of their later ability to recall “Shoe” when tested with “Foot: ????” as the cue. When, however, many other pairs intervened between seeing “Foot: Shoe” and having to generate “Shoe” to “Foot: S**e,” there was a large benefit of such an additional study trial.

A related idea in the domain of motor skills—sometimes referred to as the *forgetting and reconstruction hypothesis* (11)—is that learners profit from “reloading” the motor program corresponding to a given skill. Thus, for example, a golfer who practices hitting a particular shot on a driving range over and over again with the same club, perhaps with only a few seconds between shots, will tend to repeat what was done on the prior swing without actually reloading the motor program corresponding to that club and the target on the range. Switching clubs or targets from swing to swing does, by contrast, require reloading the appropriate motor program, which then enhances learning and transfer to shots on an actual golf course.

Optimizing learning: The Need to Introduce “Desirable Difficulties” (3)

As we have emphasized—because forgetting can enable learning—conditions of instruction that create difficulties for the learner—even slowing the rate of *apparent* learning—often optimize long-term retention and transfer; whereas, conditions of instruction that make performance improve rapidly often fail to support long-term retention and transfer. To the extent, therefore, that we—as students or teachers—interpret current performance as a valid index of learning, which can actually only be measured by the long-term retention of skills and knowledge, we become susceptible to choosing or preferring poorer conditions of instruction over better conditions of instruction.

As we have emphasized elsewhere (1), however, the word *desirable* is important. Many difficulties are *undesirable* during learning, after learning, and forever after. Desirable difficulties are desirable because responding to them (successfully) engages processes that support learning, comprehension, and remembering. They become undesirable difficulties if the learner is not equipped to respond to them successfully. Research on "generation effects" provides a good example. That research has demonstrated that generating some to-be-remembered item produces far better later recall of that item than does just being presented the intact item to study (e.g., 14). That finding, however, rests on the generation process succeeding. There are no such benefits if the act of generation fails—although it should be added that trying and failing enhances memory for the information when feedback is provided (see, e. g., 10).

Concluding Comments on Beliefs and Misconceptions that Impede Effective Learning.

Interpreting current performance as learning. What we can observe during instruction or practice is performance, which can be heavily influenced by cues and other features of the instructional context of instruction that are unlikely to be present when some skill or knowledge is needed later in a real-world setting. The distinction between *learning*, which can only be assessed at a delay, and *performance*, as indexed by the probability or speed of producing to-be-learned facts or skills during instruction or practice, is a time-honored distinction in research on learning, one that traces back to the 1930s. Early research with both humans and animals showed that learning could actually be happening during periods when performance was not changing, and more recent research has demonstrated that the converse is true as well—namely, that little or no learning can be happening in certain circumstances even though performance is increasing rapidly (for a recent review of research on the learning-versus-performance distinction, see 16).

Misunderstanding the meaning and role of errors. Errors, which should be viewed by both learners and teachers as an essential component of effective instruction, are often—instead—assumed to reflect inadequacies of the instructor, the student, or both. This assumption can lead students to avoid effective learning procedures, such as taking practice quizzes and asking questions in class when they are confused—and it can lead teachers to answer their own questions, to provide clues that make answering a question a quite trivial exercise, to block rather than interleave instruction on related topics, and so forth.

Underappreciating the power we all have to learn. In our view, there is a wide-spread over-appreciation of aptitude that is coupled with an under-appreciation of the power of training, practice, and experience. There also tends to be an implicit or explicit assumption that efficient learning is easy learning—that if someone will just teach us in a way that meshes with our learning style, or taps into our innate ability in some other way, learning will happen with little effort on our part.

Individual differences do matter, and matter greatly, because all new learning builds on—and depends on—old learning. In addition, personal, family, and cultural histories can affect such things as our motivation to learn, the degree to which learning is valued; and the aspirations and expectations we have with respect to our acquiring skills and knowledge.

In short, individual differences *do* matter, but optimizing learning and teaching rests on our understanding of what we *all* share: An unintuitive functional architecture as learners and a remarkable capacity to learn.

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