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## Using Testing to Improve Learning and Memory

Henry L. Roediger, III, Kathleen B. McDermott,  
and Mark A. McDaniel

Washington University in St. Louis

### ► *Please describe your current position and research interests.*

Henry L. Roediger, III: I am the James S. McDonnell Professor in the Department of Psychology, Washington University in St. Louis. All three of us are interested in educational applications of memory research. In addition, I study issues related to arousal of illusory or false memories and implicit (or automatic) uses of memory.

Mark A. McDaniel: I am Professor of Psychology, Washington University in St. Louis. In addition to my work on educational applications of memory research, my research focuses on prospective memory (remembering to do things in the future) as well as aging and memory.

Kathleen B. McDermott: I am Associate Professor of Psychology, Washington University in St. Louis. In addition to our educational applications work, I study illusory memories, the neuroimaging of memory using functional magnetic resonance imaging (fMRI), and episodic future thought (how people use memory to think about possible future events).

### ► *How did you get interested in how testing could be used to enhance learning?*

All three of us had been involved in basic laboratory research on the effects of testing memory. These effects are often powerful and many studies showed that successful retrieval during testing has a greater impact on long-term retention than does repeated studying. A natural next step was to ask if we could improve students' performance in the classroom from our program of test-enhanced learning. Of course, we also encourage students to use self-testing as a study strategy to promote good retention.

### ► *What has been the real-world impact of this work?*

Our work has encouraged teachers at every level from elementary school to college and medical school to begin using more frequent testing in their courses and to tell their students about self-testing as a study strategy. However, we hope to reach a wider audience as our research program matures and we can reach an increasing number of people.

How do you prepare for a test? If you are like most students, rereading your textbook—accompanied by underlining or highlighting—is your preferred study strategy. Perhaps you underline or highlight important points the first time you read a chapter, and maybe you reread critical parts that you marked earlier. Likely you reread your class notes, too. If these study strategies seem familiar, they are not unreasonable. Repetition often aids memory. But, unfortunately, the strategies are not particularly effective. In fact, research

shows that rereading has less influence on later memory than you might expect. In some studies, rereading was *no more effective* in improving learning than a single, initial reading (Callender & McDaniel, 2009).

Research by cognitive and educational psychologists has shown that effective study strategies exist, although most require more effort than simple rereading. Relating new information to what we already know, a strategy called elaboration, can make the material meaningful and, therefore, memorable. Similarly, when we outline or take notes, we recode the information—putting it in our own words—and much research shows that such active generation improves retention. Converting verbal information into vivid mental images can also improve learning. Spacing study sessions rather than massing them together also aids long-term retention. Research evidence strongly supports the effectiveness of these and many other active inquiry strategies in mastering information (McDaniel & Callendar, 2008).

Research in our laboratories at Washington University in St. Louis has led us to advocate an additional strategy, which we call test-enhanced learning. As you read text material, make up questions (or use the ones supplied at the end of the chapter) and then later test yourself. If you can retrieve the information from memory, great; having retrieved it once, you will remember it even better. If you can't retrieve the answer, study the material again and retest yourself until you're sure you know it. But even if you are able to retrieve the answer once, don't stop. Test yourself repeatedly and keep retrieving answers. Repeated retrieval is the key to long-term retention (Karpicke & Roediger, 2007).

Our advice regarding test-enhanced learning represents the bottom line of this essay. In the next few pages, we'll describe some evidence that supports our advice (McDaniel, Roediger, & McDermott, 2007; Roediger & Karpicke, 2006a, b).

## Test-Enhanced Learning

Most students and teachers think of tests as assessment devices, designed to measure what students have learned and to provide a basis for assigning grades. In many college courses, especially large introductory courses, tests are infrequent, occurring perhaps two or three times a semester. Assessment is a perfectly valid reason for testing, but, as we have said, it can also improve learning.

Consider the powerful testing effect we recently demonstrated in an experiment comparing three groups who were asked to use different methods to study brief prose passages such as what you might encounter in a textbook. All participants read the passage once. Then one group (SSSS) studied the passage three more times; a second group (SSST) studied the passage two more times and then took one test; a third group (STTT) took tests on the passage three successive times after reading it once. When tested, participants simply recalled as much as they could, but because the tests were relatively immediate and the passages were reasonably short, they were able to recall

later memory than you might expect. Research has shown that effortful retrieval is more effective in improving learning (McDaniel, 2009).

Psychologists have shown that effortful retrieval requires more effort than simply reading. When we study something new, we often try to connect it to what we already know. For example, when we study a new material meaningful and, therefore, we often take notes, we recode the information in our own words—and much research shows that this helps. Converting verbal information into a different format improves learning. Spacing study sessions also aids long-term retention. The effectiveness of these and many other strategies for storing information (McDaniel &

Roediger & Karpicke, 2006b) is supported by research from Washington University in St. Louis. We call this test-enhanced learning. We have developed several strategies (or use the ones supplied at the end of the book) for yourself. If you can retrieve the information once, you will remember it better. If you can retrieve it a second time, you will remember it even better. But even if you are able to retrieve it a third time, you will remember it even better. Repeated retrieval is key to long-term retention (Karpicke &

Roediger & Karpicke, 2006b). Learning represents the bottom line of the process. We describe some evidence that supports this. (Roediger & Karpicke, 2006b)

Tests as assessment devices, designed to provide a basis for assigning grades in large introductory courses, tests are given three times a semester. Assessment, as we have said, it can also improve learning.

We recently demonstrated in an experiment that we were asked to use different methods of studying what you might encounter in a text. We had three groups. One group (SSSS) studied the passage once. Then one group (SSST) studied the passage twice. The third group (STTT) took tests on the passage after studying it once. When tested, participants in the SSST group did best, but because the tests were relatively short, they were able to recall

about 70 percent of the information. Importantly, no feedback was given on test results (Roediger & Karpicke, 2006b).

Then participants took a break. For some participants, the break lasted only 5 minutes; others were asked to come back to the laboratory after a week. How did the different study conditions affect later recall? As you can see in Figure 1, when tested after 5 minutes, the more students had studied, the better they did—evidence that cramming just before the exam can actually work! However, after 1 week, the outcome was completely reversed. Now students who had studied only once but recalled the material three times did best; those who had studied it three times and were tested once were next best; and those who had studied material the most but were never tested performed worst. The clear implication is that for long-term retention—the kind educators hope to foster and students seek—repeated retrieval of material is better than reading it over and over.

The finding that the act of taking a test can enhance learning may seem surprising, but convincing supporting evidence has been reported in many different experiments over the years (see Roediger & Karpicke, 2006a, for a review of the literature). In fact, you can probably find confirmation in your own elementary school experience. Think back: What strategies were suggested for learning multiplication tables, foreign language vocabulary, or other systems of material? You probably used some type of flash card with the problem or word visible and the answer hidden. Did you practice over and over until the information was so well learned that answers would immediately spring to mind? Such self-testing can be adopted for almost any type of material and can create effective means for learning large amounts of information and retaining it for long periods of time.

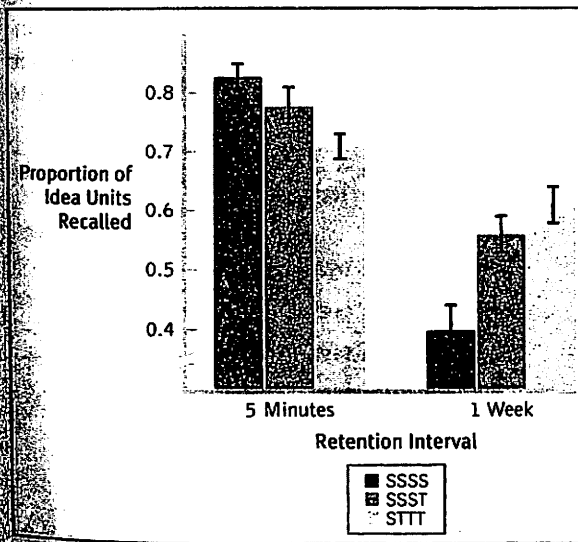


FIGURE 1 Proportion of ideas recalled after 5 minutes and after 1 week as a function of three experimental conditions. The data on the left side show recall on the final test given after 5 minutes; the data on the right, results after 1 week. (Roediger & Karpicke, 2006b)

## The Importance of Feedback

Participants in the test-enhanced learning experiment did not receive feedback after taking the test. As we noted, however, the first tests were given under conditions in which memory performance was reasonably good. Thus, we wondered whether the testing effect would occur under conditions where memory performance is mediocre or poor. Interestingly, the answer is *no*, or at least *not always*. If students are given a test on a large amount of material or if they are given a test long after the material has been studied, the testing effect disappears (Kang, McDermott, & Roediger, 2007). In fact, if performance on the test is very poor, the test offers no benefit at all.

Suppose a test, given under conditions of poor recall, is followed by feedback (that is, correct answers). How will performance on a retest compare with a condition in which untested participants simply read correct answers in advance? To answer that question, we asked students to read four brief articles about topics in psychology. Each article had a different follow-up: a multiple-choice test, a short-answer test, a reading task involving the material that was tested in other conditions, or no activity (the control condition). The design of the study is shown in Figure 2. Because they were unaware there would be follow-up, all participants were presumed to have studied the articles in the same way (Kang et al., 2007, Experiment 2). To further account for unexpected influences, information in the questions was carefully controlled. For example, one short-answer question was, "What is hostile media bias?" The multiple-choice question was the same, but four possible answers were provided. The reread-condition statement was, "Hostile media bias refers to the phenomenon in which people on both sides of a controversy perceive the media as being hostile to their group." Students who took the short-answer or multiple-choice test received feedback that consisted of statements like those presented in the reread condition. Students in the reread condition read statements for a third time to equalize exposure to

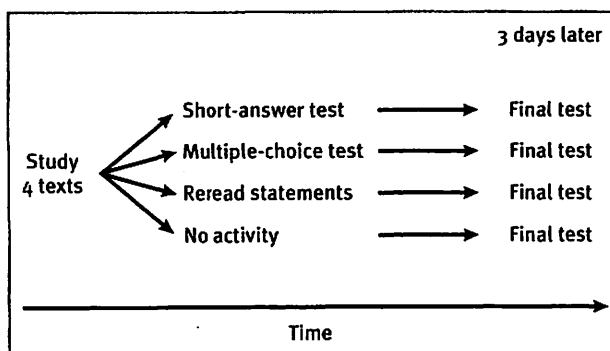


FIGURE 2 The design of the Kang, McDermott, and Roediger (2007) experiment. Students studied a passage and then either took a short-answer test, took a multiple-choice test, reread certain facts, or had no activity related to the passage. They took a final test 3 days later.



Quizzing can also improve retention of related but untested information (Chan, McDermott, & Roediger, 2006). If verified, this finding has important implications for learning: Because only a small amount of material can be quizzed, a large part of the content of college courses is not tested. The possibility that self-testing might aid in the retention of material that instructors don't get around to quizzing is a comforting notion.

### Does Testing Work in the Classroom?

You may be wondering whether our laboratory research evidence has real-world relevance. After all, college students study for varying amounts of time and in different ways, and the time between classroom quizzes and a final test are much longer than they are in typical lab studies. We wondered about that, too. And the answer is *yes*, at least in the first studies that have asked this question.

A Web-based course on brain and behavior at the University of New Mexico was the site of one of these experiments (McDaniel et al., 2007). Students in the course, who were assumed to have completed 40-page weekly reading assignments, were assigned to the now-familiar four conditions: short-answer quizzes, multiple-choice quizzes, the opportunity to reread, and no intervention at all (control condition). Because this was a real class, of course, some students may have read the assignment multiple times, some once, and some not at all. Feedback was given after the quizzes and again for the third (read facts) condition in which students read the facts a second time to equate for exposure.

After three assignments had been completed, students took a multiple-choice unit test. The content was the same but the wording of the questions was changed, thus requiring different answers. For example, in the multiple-choice quiz, students were asked, "All preganglionic axons, whether sympathetic or parasympathetic, release \_\_\_\_\_ as a neurotransmitter." (The correct answer is acetylcholine.) On the unit exam, the question was "All \_\_\_\_\_ axons, whether sympathetic or parasympathetic, release acetylcholine as a neurotransmitter." Thus, students could not memorize answers from the quiz, but had to know the whole fact. Students in the two groups that had been quizzed did better on the unit exams (54 percent correct) than those in the other two groups (46 percent correct). Again, the short-answer format offered a better opportunity for retention than did the multiple-choice format, with the latter format leading to only slightly better retention than rereading, and rereading proving superior to no re-exposure at all. In short, the results of the classroom study agree remarkably well with those of the laboratory study, as well as with other laboratory results (see, for example, Butler & Roediger, 2007). Keep in mind that the lab experiment used short-answer items as the final test, whereas the classroom experiment used multiple-choice questions. We find it reassuring that the same pattern of results holds with both types of test.

In current research in three middle-school classrooms, we have also found strong testing effects. Students in social studies, for example, achieved scores

n of related but untested information). If verified, this finding has important implications. Only a small amount of material in college courses is not tested. The possible retention of material that instructors are assuming is a troubling notion.

## Classroom?

Laboratory research evidence has shown that students study for varying amounts of time between classroom quizzes and exams, as in typical lab studies. We wonder, however, at least in the first studies that have

examined behavior at the University of New Mexico (McDaniel et al., 2007). Students have completed 40-page weekly reading assignments under four conditions: short quizzes, the opportunity to reread, and so on. Because this was a real class, of course, assignments were given multiple times, some once, and some after the quizzes and again for the third time. Students read the facts a second time to equate

to completed, students took a multiple-choice test. The questions were the same but the wording of the questions was different. For example, in the multiple-choice test, the question was "All preganglionic axons, whether sympathetic or parasympathetic, release acetylcholine as a neurotransmitter." (This was the unit exam, the question was "All sympathetic or parasympathetic, release acetylcholine.") Students could not memorize answers to the whole fact. Students in the two groups that took the unit exams (54 percent correct) than those that did not (48 percent correct). Again, the short-answer test showed better retention than did the multiple-choice test, going to only slightly better retention than the multiple-choice test. In short, the results are remarkably well with those of other laboratory results (see, for example, Roediger et al., 2007). We find that the lab experiment used short-answer questions as the classroom experiment used multiple-choice questions, assuring that the same pattern of results

was observed in school classrooms, we have also found similar results in lab studies, for example, achieved scores

about 10 points higher on material on which they had been quizzed than on material that was not quizzed (Roediger et al., 2007). Quizzing helped raise grades a letter, from B- to A- levels.

## Practical Implications for How to Study

One of us (KBM) teaches an undergraduate course on human memory, which meets twice a week for an hour and a half. As in most classes, readings are assigned for that day, and the lecture builds on and supplements the readings. However, unlike most classes, the last 5 to 10 minutes of the class are devoted to a quiz, with questions drawn from everything assigned as a reading for that day and from the lecture. Students also take three regular tests and a final exam. The news about the quiz schedule always leads a few faint-hearted students to drop the course. However, by the end of the semester, students' reactions are mostly quite positive.

Of course, as a student, you are in no position to tell the instructor how many tests to give, and it would take an unusually brave student to even broach the idea of an instructor giving more tests. How can you use the information we have provided to craft more effective study strategies for yourself? In providing advice, we draw on research not discussed in this essay (see McDaniel & Callender, 2008, for a summary) to provide advice on how to read your textbook and get the most from it, how to best use lectures and lecture notes, and how to review prior to tests.

Reading a textbook may seem obvious and easy, but effective reading requires a strategy sometimes called the PQ4R technique: *Preview, Question, Read, Reflect, Recite, Review*.

- **Preview.** Skim through the chapter, looking at the headings and the figures to see what topics will be covered. If there are summaries, read them first to see where you will be heading. Also, see if there is a set of key terms and review questions at the end of the chapter, and possibly other study aids.
- **Question, Read.** If there were no key terms and no questions, make them up as you go along. List the important terms and write the definitions.
- **Reflect.** Read with an inquiring mind: Try to convert headings into questions that will be answered. So, if one heading is "Classical conditioning" ask yourself, "What is classical conditioning?" and your reading will answer that question. Jot down these questions to help you with later study and review. Some students find it worthwhile to outline chapters as they are reading, which forces them to think hard about the relationship among sections of a chapter and produce it in their own words.
- **Recite, Review.** Reading carefully takes longer than simply blasting through the chapter with a highlighter, but studies show that students remember the material much better when they have carefully

considered it this way. At the end of the chapter, review the key terms (either provided in the book or collected by you). Look up and restudy any terms about which you are shaky. If you can't remember it just after you have read it, what chance will you have on a test later? Similarly, review the study questions and try to answer them. Again, review (or give yourself feedback) on questions you cannot answer.

Paying careful attention and taking good notes in class is an art that some students master and others do not. We suggest regular class attendance, focused listening, copious note taking, and careful attention to the instructor's suggestions. These steps may seem obvious, but, surprisingly, many students view them as optional. After a class, read over your notes carefully. You were writing fast, at least some of the time, so you should go over the notes while the lecture is still fresh in your mind and flesh them out. Or, if you were taking notes on your laptop, you may need to edit them to extract key points.

Treat your notes the same way that you read the text: Cull out key terms and think of possible review questions. What the teacher covers in class is often what she or he considers most important and is therefore likely to include on the test. For some parts of the lecture that you might have found confusing, consult your notes, the Internet, or your instructor during office hours.

If you have thoughtfully studied your text and class notes, preparing for exams should be relatively easy. But, as should be clear by now, repeatedly rereading your text and notes is not a particularly effective strategy. Pre-exam time is the moment to put into practice our test-enhanced learning method. Test yourself on key terms and definitions. Examine the review questions in the book or the ones you created. If you are unsure of the meaning of a term or can't answer a question, review the book, your lecture notes, or both. Keep questioning yourself until you have the information down. By testing yourself, you can help gauge whether or not you know the material.

Repeated rereading can make information seem quite familiar without making it easy to retrieve when you need it—on the test. Repeated retrieval is the key to long-term retention (Karpicke & Roediger, 2007). So, even if you think you know the answers to questions, if you keep practicing retrieving them at spaced intervals, you will remember them better over the long term. Self-testing not only aids learning, but it also lets you know what you do not know and where you need to focus your efforts.

## Conclusion

Repeated retrieval makes information more likely to be accessible in the future. Testing in the classroom accomplishes this goal, but so does studying by self-test. As William James wrote (1890, p. 646), "A curious peculiarity of our memory is that things are impressed better by active than by passive repetition. I mean that in learning (by heart, for example), when we almost know



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look at the book again. If we recover the words in the former way, we shall  
probably know them the next time; if in the latter way, we shall very likely  
need the book once more."

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Department of Education.

## Suggested Further Reading

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