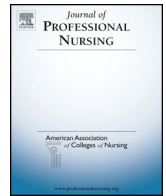




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Testing enhances learning: A review of the literature

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ABSTRACT

The retrieval of information from memory through testing produces learning advantages that are superior to studying alone; a phenomenon called the testing effect. Despite strong and consistent evidence that testing improves retention and recall of information, and superior organization of information within memory, testing continues to be under-utilized as a pedagogical strategy by teachers and as a self-regulatory strategy by learners. Testing that promotes recall rather than recognition of information, that is repeated at intervals over time, and that is accompanied by feedback is optimal for promoting learning. In addition to using testing as a powerful teaching tool, educators should promote the use of self-testing by learners to support the life-long learning that is essential to professional practice.

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Introduction

The use of testing to evaluate learning is well known to educators. The primary purpose of such summative testing, usually conducted at the end of a course or a course of study, is to provide evidence of learning *outcomes* (Kibble, 2017). In the health professions, summative tests in the form of licensure and specialty certification examinations also fulfill a duty of accountability to the public; they attest that those who have met the test standard are able to provide safe, competent care (Norcini

et al., 2011). Summative tests do not usually provide feedback beyond a grade or a pass-fail result; therefore, their utility to enhance learning is limited (Norcini et al., 2011). The use of testing to *promote* learning is less familiar to educators and to learners. Testing or retrieval practice is one of the “desirable difficulties”: practices that increase the perceived difficulty of learning but that enhance long-term retention (Bjork, 1994). The testing effect—the observation that retrieving information from memory strengthens both the durability of that information within long-term memory and the ability to retrieve it in the future—is one of the most robust phenomena in cognitive psychology. Yet, teachers and learners alike may not draw upon the testing effect to support learning. In this narrative review, I will summarize the

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evidence for the direct and indirect effects of testing and discuss the mechanisms thought to underlie the learning benefits conferred by testing. I will advance suggestions as to why the testing effect is under-utilized by teachers in organizing training and development and by learners in regulating their own learning. Finally, I will describe the testing practices, endorsed by current evidence, that educators may use to promote learning in the classroom and in the clinical area and that they may encourage learners to use to support their own life-long learning.

Search strategy

The purpose of this narrative review is to provide a synthesis of the evidence concerning the testing effect. The psychology and educational literatures were searched via the ERIC and PsycInfo databases, using search terms “test-enhanced learning”, “testing effect”, and “retrieval practice”. The health sciences education literature was searched via the PubMed and CINAHL databases, using the same search terms. Searches were limited to full-text, English-language publications of studies involving human subjects. Commentaries and editorials, and studies reporting on individuals with neurological disorders were excluded.

The direct effect of testing on learning

A consistent finding in the memory research literature is that long-term retention of information is improved by testing compared to re-studying, even when more time is spent studying than attempting to retrieve the material through testing (Einstein, Mullet, & Harrison, 2012; Karpicke & Roediger, 2008; Roediger & Karpicke, 2006a). The act of retrieval itself, rather than repeated exposure, reinforces memory: This is the *direct* effect of testing. Evidence for the direct effect of testing has been found among diverse populations of learners, including elementary school children (Jaeger, Eisenkraemer, & Stein, 2015; McDaniel, Thomas, Agarwal, McDermott, & Roediger, 2013; Rohrer, Taylor, & Sholar, 2010), college students (Carpenter & Pashler, 2007; Dobson & Linderholm, 2015; Jacoby, Wallhheim, & Coane, 2010; Roediger & Karpicke, 2006b), and professional trainees (Baghdady, Carnahan, Lam, & Woods, 2014; Larsen, Butler, & Roediger, 2013). The testing effect has been demonstrated for both word lists and paired-associate words in laboratory experiments (Grimaldi & Karpicke, 2012; Karpicke & Roediger, 2008; Pyc & Rawson, 2009), for more complex, authentic classroom learning involving prose passages (Einstein et al., 2012; Roediger & Karpicke, 2006b) and for non-verbal learning tasks (Carpenter & Pashler, 2007; Jacoby et al., 2010). The generalizability of the testing effect to diverse populations of learners suggests its utility in both undergraduate nursing education and post-licensure nursing education, and in the classroom and in the clinical area.

The predominant experimental finding is that performance on immediate tests is better after re-study than after practice testing, but that performance on delayed tests is better after practice testing than after re-study. These findings suggest that the difficult retrieval induced by practice, as indexed by performance on an immediate test, produces superior long-term retention compared to re-study (Rowland, 2014).

Several explanations advanced for the testing effect have in common the idea that testing promotes an active, effortful mental search for concepts or concrete examples that are meaningfully related to the target item and that are used as retrieval cues (Carpenter, 2009; Rowland, 2014). Repeated retrieval practice is thought to result in the storage in memory of retrieval cues along with the target item, so that multiple routes of access to the target item are available; relevant cues are reinforced and irrelevant cues are suppressed with repeated retrieval (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Karpicke & Blunt, 2011). For example, in learning about the 12 lead electrocardiogram, one goal of instruction is that students become able to identify the leads associated with particular regions of the heart and the

corresponding coronary arteries. Thus, the terms “lateral wall”, “circumflex artery” and “leads I, aV₁, V₅ and V₆” serve as mutually reinforcing retrieval cues, while “right coronary artery” and “leads II, III, and aV_f” are recognized as irrelevant cues when considering the lateral wall of the heart. Testing using different questions to elicit the same knowledge promotes the formation of multiple retrieval routes to that knowledge within memory, increasing the likelihood of successful future retrieval (Butler, 2010). Examples of such questions might be, “What leads reflect electrical activity of the lateral wall of the left ventricle?” and “What leads do you expect will show manifestations of lateral wall ischemia?” and “Your patient has had a stent placed in the circumflex artery. What leads should you select to monitor for in-stent stenosis?”

Recent neuroimaging studies have demonstrated enhanced connectivity between the areas of the brain that exert control over attention and memory during testing compared to re-studying, as well as greater activation of brain areas that are the site of semantic processing or processing of meaning (van den Broek et al., 2016). Therefore, there is both behavioural and neuroimaging support for theories that ascribe the testing effect in verbal learning tasks to effortful retrieval and the search for words and concepts that are meaningfully related to the to-be-learned material. The cognitive mechanism of a testing effect in visual learning tasks; however, remains unclear.

Indirect effects of testing on learning

Testing has been found to have a number of beneficial effects upon learning that are not directly related to retrieval; i.e., indirect or mediated effects. Testing influences learners' study efforts: If testing is conducted frequently, learners are more likely to study more—and more often—instead of immediately prior to a summative test (Roediger & Karpicke, 2006a). In a finding that will come as no surprise to educators, learners have reported paying greater attention when they know that they are to be quizzed on material presented in the classroom (Lyle & Crawford, 2011).

Testing appears to enhance subsequent encoding of information; that is, the conversion of sensory input into memory. Grimaldi and Karpicke (2012) found that students who attempted to guess a target word using a cue word improved performance for recall even when the guess was incorrect. They surmised that the creation of a “search set” of candidate words or concepts enhanced encoding of the correct target word when it was presented for study. This finding was also seen in a study using texts in an authentic educational context (Richland, Kornell, & Kao, 2009). Arnold and McDermott (2013) found that subjects who were tested five times between study opportunities; i.e., study-test-test-test-test-test-study, compared to those who alternated test and re-study opportunities; i.e., study-test-study-test, retrieved more novel words presented for learning, suggesting that testing primed subsequent recall. Similarly, Wissman, Rawson, and Pyc (2011) found that students who were tested after reading each of two prose passages scored better on a test of recall of information from a third passage compared to students who were only tested after reading the third passage. Zaromb and Roediger (2010, experiment 2) found that subjects who were tested on their recall of a list of randomly presented words demonstrated not only greater recall of individual items on a delayed test, but a greater degree of organization of those items into categories than did subjects who spent an equivalent duration of time studying the same word lists. Thus, it appears that testing primes the brain to receive, encode, and organize information. To create benefit from the priming effect of testing, teachers could hold a “pre-test” prior to a lecture.

Feedback, or knowledge of test results, may allow learners to strategically allocate study to areas in which testing shows a need for improvement (Son & Kornell, 2008). Learners devote more time and attention to review when there is a discrepancy between their expectations and their results; i.e., both when they incorrectly answer a question they had believed that they answered correctly and when they

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