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a0005 # 2.43 Cognition, Memory, and Education

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p0005 Our focus in this chapter rests on the observation that much learning in the classroom consists of the acquisition of factual information. Consider college level biology. Students have to know the names and functions of typical animal and plant cell organelles, the mechanism by which plants convert light energy to chemical energy, and the way genetic information flows from DNA to RNA to protein. As well, in introductory geology, students must master knowledge of multiple characteristics of types of rocks; in political science, students need to thoroughly learn a number of characteristics associated with each of a few types of political systems; and in developmental psychology, students must learn the attributes of a variety of theories of development ([b0475] Pressley et al., 1988).

p0010 To enhance educational effectiveness, current trends in educational psychology are focusing on classroom methods that stimulate active engagement for students (e.g., clicker systems), engender collaborative problem solving (see [b0635] Wieman, 2004), and create inquiry-based environments. These are exciting and worthwhile advances. However, it remains that students are required to commit to memory tremendous amounts of information, and many struggle with this challenge. For the most part, after engaging, inquiry-based classroom activities, educators leave the student to figure out how to remember the material for the ubiquitous examination. Students can flounder at this point. Indeed, some instructors in large college introductory biology classes find that students feel that biology is a difficult and complicated subject precisely because it requires so much memorization (discussed at the Biology Leadership Conference, March, 2006).

The premise of this chapter is that the science of learning and memory offers rich and extensive literatures that provide a foundation to assist students in the challenge of remembering the vast amounts of information they are required to learn. We highlight principles from basic memory and text comprehension research that potentially carry significant implications for improving student learning. From each principle, we identify techniques and approaches that could be implemented to assist students' acquisition of material in fact-laden courses. We first examine rereading, which is a common study method used by students. The chapter then discusses various techniques to engage the learner and improve retention of the material. With basic p0015 research on elaborative processing as a springboard, we describe and evaluate educationally realistic approaches to stimulate effective elaboration, including elaborative interrogation, advanced organizers, and imagery mnemonics.

p0020 We next discuss the concept of desirable difficulty, which involves injecting difficulty into the learning environment to stimulate effective processing on the part of the learner. We review evidence that supports the desirability of difficulty but also cautions that all difficulty is not desirable. From this work we develop theoretical guidelines for determining what kinds of difficulty are indeed desirable. Finally, we address the issues of comprehension ability and individual differences (such as the amount of prior knowledge a reader possesses) and how these factors interact with the basic learning techniques.

p0025 Throughout the chapter we highlight both the principles that potentially carry significant implications for improving student learning and the techniques that could be implemented to assist students. This cannot be an exhaustive review. Accordingly, we focus on principles and techniques for which there is translational research using educational materials so that we can evaluate the effectiveness of those principles and techniques for educational practice (cf. Naveh-Benjamin, 1990). First, however, based on theoretical and empirical work we examine the soundness of a study activity that appears to be predominant among students.

s0005 2.43.1 Is Rereading an Effective Way to Learn?

p0030 Many students report that their typical study activities involve rereading text (Goetz and Palmer, 1991; Carrier, 2003) and lecture notes (see Sikorski et al., 2002; Karpicke et al., unpublished data), and rereading is advocated as a study method by researchers (Howe and Singer, 1975; Mayer, 1983; Amlund et al., 1986; Barnett and Seefeldt, 1989; Krug et al., 1990;). Based on some theoretical approaches to text comprehension, rereading would be expected to increase learning and memory for the read material. The basic premise is that different processing occurs during a second reading than the first (Millis et al., 1998; Stine-Morrow et al., 2004).

p0035 More specifically, the initial reading is presumably used to establish the surface (lexical and syntactic features) and textbase (network of propositions) levels of representation, and the second reading is used to construct a situation model (a representation integrating text content, relevant knowledge, inferences, summary statements, casual relations) of what the text is about (Millis et al., 1998). The general idea is that a limited pool of resources is available while reading, and during the initial reading, those resources are allocated to lower level processes such as word recognition, extraction of propositions, and establishing coherence among propositions. The second time the text is read resources are freed and able to be allocated to higher level (situation model) processing (see Millis et al., 1998; Stine-Morrow et al., 2004 for findings supporting this theory).

This theory is not without dispute, however. Dunlosky and Rawson (2005) measured resource allocation to particular levels of representation, using word frequency (corresponding to the surface level), the number of propositions and new arguments nouns (corresponding to the textbase) and sentence importance (corresponding to the situation model) to predict reading times. Based, on Millis et al. (1998), reading times should increase for the situation model measures but not for the surface level measures on a second reading. Dunlosky and Rawson, though, found that the regression coefficients for the sentence importance (situation model) predictor actually decreased for the second reading. p0040

Additionally, researchers have found that a situation model changes very minimally with additional processing time (labeled a rigid situation model). Along these lines, Mannes (1994) found that when the same text is read multiple times, the same inferences are made, and the same connections between topics are formed. In a similar vein, some theorists believe that most readers adopt a lazy approach to constructing a representation from read material, avoiding processing that is not straightforwardly afforded by the text (e.g., see Fletcher and Bloom, 1988). Consequently, improvements in learning from texts may require more than rereading: additional presentations of the material may need to force the student to generate information not ordinarily extracted from reading alone. We examine this possibility in detail in a subsequent section of the chapter. p0045 AU2

The educational psychology literature reflects the cloudiness of the theoretical positions on this issue. Generally, the conclusion is that while it is better to use methods that engage the reader more than simply a second reading of the text, rereading can improve performance on tests of comprehension and memory p0050 for the text. This conclusion, however, should be accepted cautiously, as not all of the evidence is supportive of this conclusion.

p0055 Some research has found that rereading improves performance on summative assessments. For instance, Amlund et al. (1985) found a benefit of rereading a text on cued and free recall tests over main ideas and details. Participants read a text either one, two, or three times (a between-subject factor) and took an immediate test over the text, as detailed above. The immediate test revealed that reading twice improved performance as compared to reading once for both main ideas and details (as evidenced by both criterial tests). Likewise, Durgonoglu et al. (1993) investigated rereading of fables and found that when answering text-based comprehension questions, reading the text twice in a spaced manner produced better performance than reading once or reading the text twice in succession. However, not all the results support the idea that rereading improves performance on comprehension tests, as there was no difference between the read-twice groups and the read-once group on questions requiring inferencing and integrating background knowledge with the text to answer the question. Further, Rawson and Kintsch (2005) showed in two experiments that massed rereading improves performance on an immediate test and spaced rereading improves performance on a delayed test. Interestingly, there was no difference between spaced and once-read on the immediate test, and no difference between massed and once-read on the delayed test.

p0060 AU3 More surprising results were reported by Callender and McDaniel (unpublished observations). In a series of four experiments, five different texts were read and reread by participants and multiple-choice and short-answer questions were answered (or in one experiment, a summary was generated). Only one text showed a small benefit of rereading on multiple-choice questions, a benefit that was not replicated in other experiments of the study.

p0065 One difference between Callender and McDaniel (unpublished observations) and the studies reviewed above is the texts used in the studies. Callender and McDaniel attempted to increase the educational relevance of the study by using textbook chapters and assessments like those used by educators. Previous studies have been more limited in their applicability to educational settings, particularly with respect to three aspects of the research: the assessment/criterial test used, text characteristics, and learning instructions.

With respect to the assessment or criterial test used, educational assessments use multiple-choice or short-answer assessments (Bol and Strage, 1996; Jackson, 2005) rather than free recall (Mayer, 1983; Amlund et al., 1986; Krug et al., 1990). Additionally, educational assessments focus on assessing gist-based representations rather than verbatim recall of text (Bol and Strage, 1996) as tested in the laboratory using a cloze test (filling in missing words from a text; Rothkopf, 1968) or verifying if a particular sentence was in the original text (Howe and Singer, 1975; Mayer, 1983; Haenggi and Perfetti, 1992). Educational texts tend to be longer than texts used in the laboratory (99 words [Glover and Corkill, 1987] to 1770 words [Rawson and Kintsch, 2005], with most texts much shorter than 1770 words [see Howe and Singer, 1975; Mayer, 1983; Amlund et al., 1986]). Finally, learning in educational settings is usually intentional rather than incidental (Mayer, 1983; Amlund et al., 1986; Durgunoglu et al., 1993). Comprehension processes could differ when the reader has knowledge of test and study method as opposed to when the reader is uninformed. p0070

A simple conclusion from this research is that rereading has not been established as a beneficial study method in educational settings. Considering that rereading is time intensive (Callender and McDaniel, 2007) and provides little benefit, there may be superior methods for students to use in educational settings. p0075

2.43.2 Improving Learning and Retention in Education: Elaborative Processing s0010

Memory research has established that elaborative rehearsal produces learning and retention. Elaborative rehearsal is an umbrella term that encompasses a variety of processes including verbal elaboration (Craik and Tulving, 1975), organization (e.g., Bower, 1972; Bellezza et al., 1977), and visual imagery (McDaniel and Pressley, 1987). The following sections will focus on each of these processes in terms of their potential educational applications. Again, by necessity this is a selective presentation that emphasizes reasonably direct translation of basic memory findings to learning with educationally relevant materials and content. p0080 s0015 ### 2.43.2.1 Verbal Elaboration

p0085 A long-standing issue in the literature on verbal elaboration concerns the characteristics of elaboration that facilitate learning. In this regard, one line of work that seems especially pertinent for education stems from the observation that many facts seem arbitrary to students, because students do not have the expert knowledge base to understand the significance of the facts (Bransford et al., 1982). To mimic this situation in the laboratory, Stein et al. (1978; Stein and Bransford, 1979) required subjects to study a set of sentences that paired certain identifying attributes to specific actions:

1. The diamond was too expensive for the slow man
2. The child was comforted by the short man

p0090 To increase memory for the association between a particular man and a particular action, one general approach could be to stimulate elaboration by expanding the target information in a semantically congruous fashion (cf. Craik and Tulving, 1975) as follows:

1. The diamond was too expensive for the slow man to hand down to his son
2. The child was comforted by the short man who sat around a lot

p0095 However, these semantically congruous elaborations did not improve memory for the associations presented in the base sentences (33% recall with semantic elaborations versus 49% recall with base sentences). Instead, Stein et al. (1978) demonstrated that elaboration of these arbitrary associations was effective when it reduced the arbitrary nature of target information – when it precisely specified the nature of the target relations. Specifically, the elaborations below, which specified the significance of the relations in the sentences, significantly improved memory for the 'man' sentences to 69% correct (see Bradshaw and Anderson, 1982, for similar findings with real-world target facts).

1. The diamond was too expensive for the slow man who was fired from his job
2. The child was comforted by the short man who looked the child in the eye

p0100 In relation to education, consider that many of the facts presented to students may appear as arbitrary as the base 'man' sentences were to subjects in the laboratory experiments. For example, in a biology class in primary school, students may be required to learn that veins have thin walls and arteries have thick, elastic walls, or that plant cells have mitochondria. At a conference on improving biology education, one of us recently overheard a biology instructor lament, "We beat it over students' heads, 'plant cells have mitochondria.' Why can't they learn?" By the present analysis, it is because these relations are essentially arbitrary to the student. Accordingly, a key implication from the basic memory literature is that to enhance learning in educational settings, students should be encouraged to engage in elaborative processing that reduces the arbitrary nature of the target material. One avenue would be for instructional material or the teacher to provide elaborations for the student. For instance a teacher may elaborate that arteries are elastic to withstand the spurts of blood pumped by the heart and to act as a kind of valve to keep blood from flowing backwards. In many settings, however, from grade school social studies to a college-level course, students may have to generate their own elaborations for much of the content because the books and teachers do not do so. Basic memory work suggests at least one technique for prompting students to generate elaborations that reduce the arbitrary nature of target content, a technique termed elaborative interrogation (Pressley et al., 1988).

Using laboratory materials, Pressley et al. (1987b) prompted learners to generate elaborations that would reduce the arbitrary nature of the association by asking learners to explain why the association might be exist. In one experiment, subjects were presented with the 'man' sentences and for each sentence required subjects to provide an elaboration that would answer the question 'Why did that particular man do that?' The group that generated answers to the why questions remembered significantly more of the man sentences than did a group receiving the base sentences and even a group that was provided with precise elaborations. In a subsequent experiment, Pressley et al. (1988) applied the elaborative interrogation technique to a set of Canadian civics facts that students would be expected to learn. Students who attempted to answer why a particular fact might be true (an example target fact is 'Apples were first cultivated in Nova Scotia') showed over a 50% increase in retention of those facts relative to students who read the facts (with study time kept constant across the conditions). p0105

The elaborative interrogation technique has been extended to more complex materials and contrasted against more traditional study techniques. McDaniel p0110 and Donnelly (1996, Experiment 2 presented students with short didactic passages culled from high school and college textbooks that presented astrophysics concepts such as the conservation of angular momentum. In one experimental condition, each short text was followed by a why question about the concept (Why does an object speed up as its radius gets smaller (as in conservation of angular momentum)?) This condition produced significant improvements on multiple-choice assessments focused on factual information presented in the text and on the ability to draw inferences from the presented information. By contrast, conditions in which (a) the texts highlighted key words, (b) a labeled schematic was provided to display how the key concepts in each text were related, and (c) subjects were required to generate their own schematic did not improve performance on the multiple-choice assessments relative to the basic text condition (in all cases, performance was nominally lower relative to the text condition).

p0115 Elaborative interrogation has also been applied to connected prose. Seifert (1993) hypothesized that elaborative interrogation may not be as effective with prose as with factual statements because once the facts are embedded in paragraphs, the context provides meaning. The arbitrariness of the facts is removed by the surrounding information. Elaborative interrogation, however, did improve memory for facts in the text, although the effect size was smaller than when elaborative interrogation was used with lists of facts. Similarly, Özgungor and Guthrie (2004) found a benefit of elaborative interrogation on recall and the ability to generate inferences about the text. This finding is not universal, as Boudreau et al. (1999) found no benefit of elaborative interrogation over self-selected strategies or underlining on memory for prose.

p0120 It is possible that the benefits of elaborative interrogation (and other elaboration techniques) are most prominent for individuals with lower learning and reading abilities. Along these lines, Callender and McDaniel (2007) found that elaborative interrogation provided no benefit for high ability comprehenders (as measured with the Multimedia Comprehension Battery; Gernsbacher and Varner, 1988) when answering questions about a text they had studied, but it did prove helpful for low ability comprehenders when answering test questions that targeted specific information in the text. Successful learners may spontaneously produce effective elaborations when studying and therefore need less guidance to promote elaboration (i.e., generating why) than less successful learners.

2.43.2.2 Organization s0020

An understanding of the organization of a text is also important in both comprehension processes and later retention of the text (Caverly et al., 2000). When a reader constructs a good mental representation of the organizational structure of the text, the reader is able to determine what information is essential to understanding the text, and what information is irrelevant (see Gernsbacher, 1990). This is particularly true when the text does not encourage the reader to process the organization of the individual propositions within the text (Einstein et al., 1990). p0125

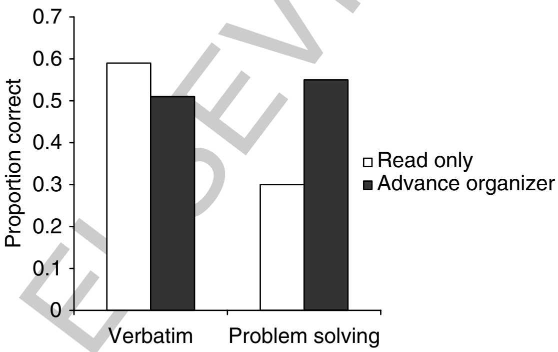
Two methods have been used to aid readers in organizing and identifying the macrostructure of the text: outlining and advance organizers. Outlining is the traditional task of creating a structure (usually hierarchical) out of the text, and advance organizers are generally short paragraphs or diagrams that introduce the concepts in the text to be read. Both of these methods provide a schema into which the text can be integrated. p0130

The rationale for using outlining (and organization in general) stems from basic work on word list recall. When seemingly unrelated words were presented and participants were forced to organize the words into categories (e.g., things that are green, liquids, and things made of wood; Einstein and Hunt, 1980), recall of the list was higher than when no organizational strategy was used (see Mandler, 1967, for similar findings). Thus, it was apparent that forcing students to organize information may lead to better recall. While categorizing words may not be used in educational settings, outlining text is a commonly used method. p0135

In a series of experiments, Einstein et al. (1990) showed that outlining improved readers' recall of expository texts. Further, similar tasks that encouraged relational processing of the text significantly improved recall a week later over a read-only control. Outlining, however, may not always result in improved performance. Some assert that outlining can improve performance on criterial tests only if the reader is taught how to outline appropriately (Caverly et al., 2000). Additionally, outlining does not automatically prompt a reader to integrate the text with prior knowledge, which is often necessary for improved performance. p0140 p0145 One way to encourage connecting the text with prior knowledge, and possibly to provide knowledge when none is possessed, is using an advance organizer (Mayer, 1987). Ausubel (1963) first developed the advance organizer as a way to provide information and orient the reader to the contents of the text (Kirby and Cantwell, 1985). The organizer serves to encourage integration of new information in the text with the reader's existing schema. For those who have no schema in place, the advance organizer provides a schema (Mayer, 1978; Tyler et al., 1983).

p0150 One view of the advance organizer is that while it provides the reader with the important information in the text, it presents it in a more abstract and general way than, for example, a summary would (Tyler et al., 1983). Others suggest that advance organizers are more effective when they provide a concrete model of the information in the text. This type of organizer does not present additional information or add anything substantive to the text, but does provide a way for the reader to organize the text. In this way, it is thought that advance organizers work as though they are just an additional presentation of the text (Mayer, 1987).

p0155 In two experiments, Mayer (1983) showed the benefits of using advance organizers with unfamiliar text. Mayer provided participants with a diagram that explained the key principles in the text, as well as a way to organize them, and allowed the students to study the diagram for 60 s before listening to the passage. The advance organizer increased overall recall of the text and improved performance on tasks that required application of the concepts (but not for tasks that required verbatim memory of the text; see **Figure 1**).



f0005 **Figure 1** Effects of advanced organizers verbatim memory and problem solving in Experiment 1 from Mayer RE (1983) Can you repeat that? Qualitative effects of repetition and advance organizers on learning from science prose. *J. Educat. Psychol.* 75: 40–49.

AU5

One important aspect of organizational methods is that individual differences greatly affect performance. The Structure Building Framework (Gernsbacher, 1990) is based on the differing abilities of readers to form a hierarchical structure out of the text and to construct substructures of information related to the central information in the text. Those who have difficulty determining the organizational structure of the text when reading develop a poor mental representation of the text, which adversely affects both immediate comprehension of the text and later recall of it. p0160

Outlining is particularly sensitive to individual differences. When outlining is taught appropriately, it improves performance of low- and average-ability readers, but adversely affects the spontaneous processing of high ability readers. When not taught, outlining only benefits high-ability readers and does not affect performance of low- or average-ability readers (Caverly et al., 2000). p0165

Effectiveness of advance organizers is also moderated by individual differences, as they are most effective when the reader lacks prior knowledge for the content of the text (Mayer, 2003). Other organizational methods may also be sensitive to individual differences. Concept maps, or graphical representations of the text that represent both content and structure of the text, are generally more effective with low-ability readers than high-ability readers (Nesbit and Adesope, 2006). However, a recent experiment conducted by the authors (in collaboration with Kathy Wildman) showed that when low- and high-ability readers were asked to complete partially constructed concept maps after every two pages of a lengthy text, completing the concept maps improved recall for low- and high-ability readers. A good understanding of the organizational structure of the text and ways to integrate this structure with existing knowledge are both key components to understanding and remembering text. Outlining and advance organizers are two simple and effective ways of accomplishing this task. p0170

2.43.2.3 Imagery s0025

A plethora of basic memory work has demonstrated that visual elaboration (visual imagery; pictorial presentations) of the referents of target material improves memory performance (see McDaniel and Pressley, 1987; Paivio, 1986, for books on the topic). For educational content, if the referent is concrete enough to generate visual imagery, then instructing p0175 learners to form visual images can produce significant gains in retention relative to a condition in which learners are simply presented the facts to learn. For instance, for learning Canadian civics facts, subjects instructed to use visual imagery recalled as many facts as those in an elaborative interrogation elaboration condition and more facts than those in the control condition (Pressley et al., 1988). Educational material with an associative component can also be depicted pictorially with potent benefits for learning (see Levin, 1985, for a review).

In the basic literature, imagery has been integrated as a key component into successful mnemonic devices, with one of these devices in particular – the keyword method – having direct application to education. The keyword method has been most touted as a method to assist in learning the meanings of vocabulary items, either in one's primary language or in second language learning. In the keyword method, a familiar word embedded in, or sounding like, the vocabulary item is identified as the keyword, and then a visual image is constructed of the referents of the keyword and the vocabulary item interacting. For example, to learn that the Spanish word *carta* means letter, a familiar sound alike English word is identified such as cart (one could also use art or car) and an interactive image of a cart and a letter is constructed (such as a cart carrying a giant letter). On a subsequent test for the meaning of *carta*, the learner identifies the keyword and reconstructs the image, from which the meaning letter can be extracted. A wealth of evidence confirms that the keyword method produces better retention of new vocabulary meaning than does a control in which learners are given equivalent amounts of study time to learn the vocabulary items (but without instruction in any particular study method) or in conditions in which the students are given semantic-based (enriched context) strategies (McDaniel and Pressley, 1984; Pressley et al., 1987a). This pattern holds for college students learning foreign vocabulary meaning (Raugh and Atkinson, 1975), unfamiliar English vocabulary items (McDaniel and Pressley), and technical terms in a college psychology course (Balch, 2005). The pattern is also found with children learning new vocabulary (Levin et al., 1982) and when the keyword strategy is implemented with mature learners in in-class settings (Pressley et al., 1982).

The keyword method is also effective for acquisition of other associative factual content that students must learn. For instance, some elementary school social studies curricula require children to learn the states and their capitals. Levin (1985) examined learning this material using a keyword method in which pictures were presented to link the keywords instead of mental imagery. For example, to learn that Annapolis is the capital of Maryland, elementary school children were presented with a picture of two apples (keyword for Annapolis) getting married (keyword for Maryland) (see **Figure 2**). This method was compared against a control in which children studied the state–capital pairings on their own. On an initial test learning was better with keyword instruction (78%) than self-study (66%), and impressively 3 days later a retest showed 96% retention of the items learned with the keyword method and only 51% retention of the items (of which there were fewer) learned through self-study. Moreover, the students indicated the keyword materials made the work more fun and they actively requested that experimenter leave the materials in the classroom once the study was concluded. There are excellent reviews of the experimental work that detail the range and robustness of the benefits of the keyword learning method (e.g., Pressley and Woloshyn, 1995, see also Pressley et al., 1987). These uniformly positive results raise the issue of why the keyword technique has seemingly enjoyed limited penetration into educational contexts. We will conclude the present section by addressing this issue.

The criticism raised against the keyword method by some educators is that it is an artificial way to learn vocabulary that produces at least two possible

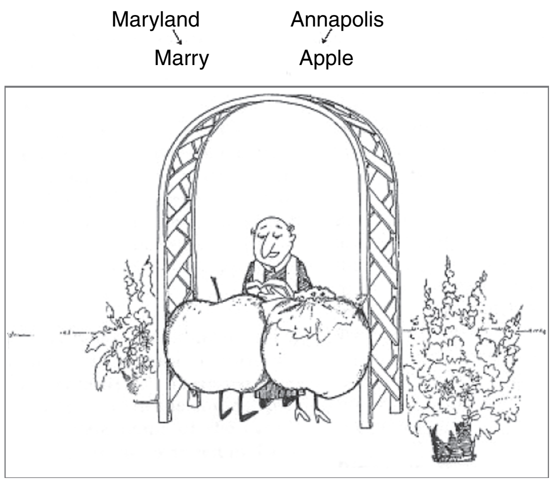


Figure 2 Sample illustration to support keyword method of learning states and their capitals (from Levin JR, McCormick CB, Miller GE, Berry JK, and Pressley M (1982) Mnemonic versus nonmemnemonic vocabulary-learning strategies for children. *Am. Educat. Res. J.* 19: 121–136).

negative consequences (a) The keyword method creates an artificial link that disrupts speed of translation and therefore slows comprehension. A particularly strong objection is that such interference in fluency perhaps could persist throughout the learner's usage of the target vocabulary. (b) It does not support acquisition of the nuances in which a vocabulary item can be used in a language, especially relative to alternative techniques of learning definitions from embedding target vocabulary in semantic contexts. However, evidence relevant to these concerns, though currently limited, does not support the above claims.

p0195 To provide initial data regarding the first concern, which is an interesting basic issue in its own right, Crutcher and Ericsson (2000) required subjects to learn 45 Spanish–English translations to 100% accuracy using the keyword method. Subjects were then timed on the speed with which they could produce the English translation given the Spanish word, and English translation given the keyword. The time to generate the English translation was significantly longer when given the Spanish word than when given the keyword, implying that when given the Spanish word subjects were retrieving two consecutive items: the keyword followed by the English translation. That is, the keyword method appeared to produce an intermediate (artificial) retrieval step. However, after extended practice at directly retrieving the English meaning, the extra retrieval step was eliminated as evidenced by (a) faster times to produce the English word when given the Spanish word than when given the keyword and (b) self-reports that before practice 80% of the learners used the keyword to mediate retrieval but after the practice period less than 15% mentioned the use of any mediator. The implication here is that if the learner continues to use the vocabulary word, the keyword mediator will be eventually eliminated from the retrieval link.

p0200 To more directly contrast the consequences of vocabulary usage following keyword versus semantic-context methods of vocabulary acquisition, McDaniel and Pressley (1989) compared the keyword condition with a semantic context-learning condition in which subjects first read the usage of the vocabulary item (an unfamiliar English word) in a three-sentence passage, then tried to infer the meaning of the item, and afterwards were given the definition. Note that this semantic context condition had a number of theoretically positive features: learners could get a sense of how the word is used in language, they processed the semantic context to attempt to infer (generate) the word's meaning, and they received direct feedback on the accuracy of their inference (e.g., see Metcalfe and Kornell, in press). Nevertheless, the mnemonic keyword method increased recall of the definition (when prompted with the word) by over 50% relative to levels achieved in the semantic context condition.

More importantly for the present purposes, after the vocabulary acquisition session, subjects were given a text to read in which 15 of the new target vocabulary items were used (none of these items had been tested in the definition recall task). Disfavoring the concern that keyword learning would slow comprehension, reading time for phrases containing the new vocabulary was equivalent for keyword and semantic context conditions. Also, the keyword method did not penalize the accuracy of comprehension: Learners in the keyword condition scored slightly better on a true-false comprehension test for the material involving the new vocabulary than did learners in the semantic context condition. In another experiment with similar learning conditions, subjects produced sentences using the new vocabulary items with as much facility after keyword learning as after semantic context learning; indeed, more sentences were correctly produced after keyword learning because more meanings were retained (McDaniel and Pressley, 1984, Experiment 2). p0205

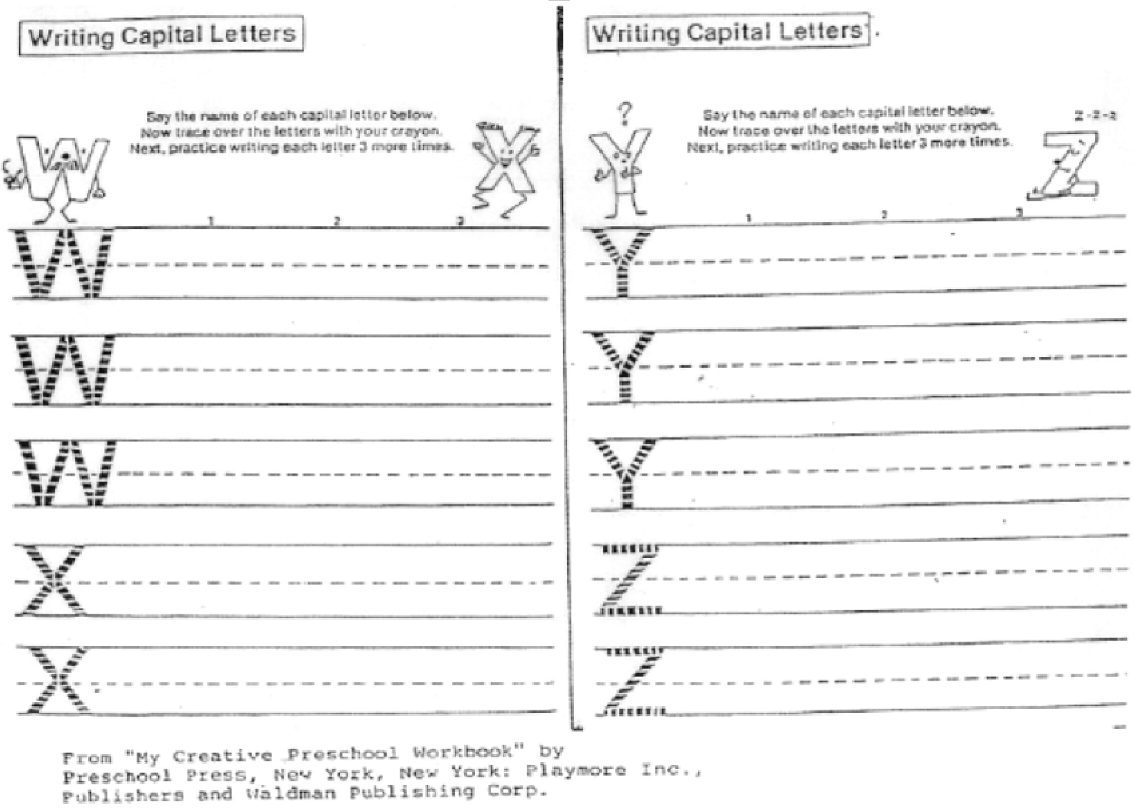
To take stock, the experimental work shows that (a) the keyword method significantly reduces the time to reach a high degree of accuracy for meaning recall relative to self-study strategies (McDaniel et al., 1987); (b) the method does not penalize comprehension and production with the new vocabulary relative to typical semantic-context learning conditions (and may enhance comprehension because more meanings are remembered after keyword learning); and (c) learning via the keyword method appears not to foster permanent reliance on the keyword link to retrieve meaning. Further, the evidence suggests that children (students) like the method. Given these positive outcomes, it is noteworthy that vocabulary learning curricula in at least some schools would be quite compatible with a keyword approach. For instance, in a public school near the authors' university, the students are given a list of new vocabulary words weekly to study for definition learning, and after several weeks the students are tested on the meanings of the target vocabulary. Here the keyword method could be straightforwardly implemented to assist the students' learning. Accordingly, educators' p0210 reservations concerning the keyword method may be misplaced. We suggest that this basic mnemonic technique could be profitably integrated into educational practice to assist learners with the burden of learning associative factual material required in many curricula.

s0030 2.43.3 The Paradox of Difficulty: Its Desirability for Learning and Retention

p0215 Students likely prefer instruction in which acquisition seems rapid and learning is easy. Similarly, instructors may evaluate their effectiveness based on the extent to which students are able to quickly demonstrate understanding of the material (and students may evaluate such instruction very positively). For instance, students and instructors may favor massed presentation of content over distributed presentation because massed presentation typically yields clear and immediate gains in performance relative to distributed practice (see Bjork, 1994). This bias in massing practice, again perhaps because it seems to foster easy, rapid learning, can be seen in standard instructional materials in elementary schools. As an example, some workbooks for handwriting repeatedly present the identical letter (see **Figure 3**), resulting in blocked practice (Ste-Marie et al., 2004).

In contrast to these practices, the experimental memory literature has established that distributed presentation is superior to massed presentation for long-term performance or recall. Indeed, a range of basic memory findings suggests that introducing difficulty or challenge into the learning environment can promote retention. Basic work reflecting this pattern includes mnemonic benefits of creating interference in the learning environment with concurrent presentation of distracting information (Battig, 1972; Einstein, 1976; Shea and Morgan, 1979), spacing of content (rather than massed presentations; see Cepada et al., 2006, for a review), and generation of material (relative to reading material; Slamecka and Graf, 1978; McDaniel et al., 1988; McNamara and Healy, 1995). p0220

With regard to educational implications, Bjork (1994) has synthesized these findings into the general notion that instructional effectiveness is significantly p0225



f0015 **Figure 3** Example of handwriting workbook with massed practice.

improved through desirable difficulties – arrangement of instruction and study activities that create difficulty for the learner. These difficulties, though slowing initial acquisition (but not preventing acquisition), are desirable in that they promote retention and transfer. The claim here is standard goals of education, such as fostering long-term retention of content, accessibility of material as contexts change, and transfer of knowledge to new situations, may be better achieved through creating difficulty for the learner – not by arranging instruction to make learning easy.

p0230 However, encouraging desirable difficulty in educational practice is a particularly provocative idea that runs counter to many instructors' intuitions and students' expectations. Accordingly, marshaling evidence for the benefits of desirable difficultly with educationally relevant content and material and developing a theoretical understanding of the kinds of difficulty that are desirable are critical steps for compelling its acceptance in educational application. To this end, we first present research examining manipulations of difficulty with educationally relevant material (see also Richland et al., 2007), and then we review theoretical work that provides a framework for specifying difficulty that will and will not be desirable.

s0035 2.43.4 Create Interference

p0235 Basic research with paired-associate lists (e.g., lists of consonant-vowel-consonant pairs such as *SIF-TOG* and *RAB-SOC*) has shown that arrangements of materials that produce interference, thereby slowing learning, can increase retention of the studied material (see Battig, 1972). Schneider et al. (2002) examined the general implication of this basic finding for learning English–French vocabulary. They varied the difficulty during training in two ways. First, the vocabulary items (and translations) were either blocked by category (five vehicles, five school items, five body parts, and so on) or mixed (one vehicle, one school item, one body part, etc.). The idea was that mixed presentation should create interference relative to blocked presentation. Second, translation direction was varied, with some learning conditions requiring that the French term be translated into English (French–English), and other conditions requiring the reverse (English–French). The latter condition is more difficult as the learner has to learn the response terms (the foreign vocabulary items) and the associative relation between the original and new language terms.

During the learning, subjects studied the vocabulary items several times and then took an immediate test to assess learning. Then 1 week later, subjects were given a retention test. The format of the retention test was varied such that some conditions were the same as during learning (intermixing/blocking of items and direction of translation) and some were reversed. The results were complex, but the general pattern was that difficulty (e.g., translation direction) impeded initial levels of learning but benefited retention and transfer. p0240

This pattern was most clearly evident for the translation direction manipulation, with the results displayed in **Figure 4**. On the immediate retention test, the more difficult English–French learning condition showed substantially reduced performance (about 50% correct) relative to the French–English condition (just under 80% correct). However, after a 1-week delay, the pattern reversed: students in the difficult English–French condition remembered more than those in the French–English condition. When considered in terms of forgetting, there was little forgetting for in the English–French condition (approximately 10% was forgotten) and dramatic forgetting in the French-English learning condition (approximately 60% was forgotten). p0245

Moreover, as shown in **Figure 5**, when the English–French condition was transferred on the delayed test to translate French items into English p0250

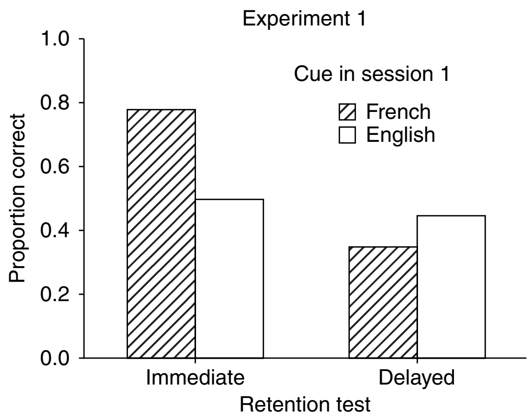
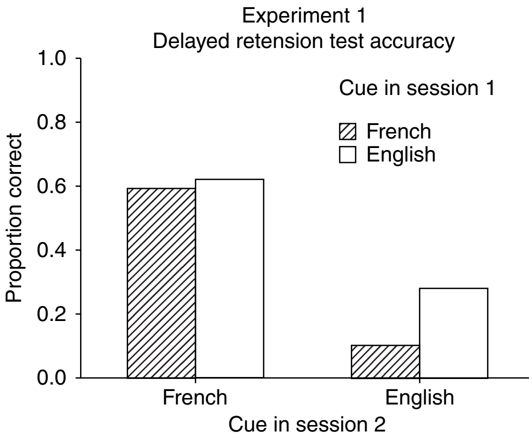


Figure 4 Immediate and delayed translation of foreign vocabulary as a function of trained translation direction in Experiment 1 of Schneider VI, Healy AF, and Bourne LE (2002) What is learned under difficult conditions is hard to forget: Contextual interference effects in foreign vocabulary acquisition, retention, and transfer. *J. Mem. Lang.* 46: 419–440. f0020



f0025 **Figure 5** Delayed translation as a function of both trained and tested translation direction in Experiment 1 of Schneider VI, Healy AF, and Bourne LE (2002) What is learned under difficult conditions is hard to forget: Contextual interference effects in foreign vocabulary acquisition, retention, and transfer. *J. Mem. Lang.* 46: 419–440.

(the unfilled bar on the left), performance was actually slightly better than for conditions that were trained to translate French items into English (the filled bar on the left). By contrast, there was exceptionally poor transfer to the reverse translation direction for French–English training (performance was under 10% correct; see the filled bar on the right). Thus, these findings with educationally relevant associative learning materials converge with the basic memory research showing that difficult learning conditions can produce desirable educational outcomes of better retention and transfer.

p0255 Creating interference during learning with more complex materials has produced similar results. Prior to reading an article on the industrial uses of microbes, learners were provided with an outline that was consistent with the structure of the text or with an outline that was inconsistent with the sequence and organization in which the content was presented in the text ([b0280] Mannes and Kintsch, 1987). Subsequent to reading the text, learning was assessed with true-false, recall, and problem-solving tests, which together yielded measures of verbatim learning and inference. Learners given the consistent outline showed more verbatim learning than those given the inconsistent outline. By contrast, learners given the inconsistent outline were better able to draw correct inferences from the information than those given the consistent outline. In this case then, interference was not effective for increasing verbatim learning but was effective for enhancing inference and application of the content, arguably a key objective for education.

2.43.4.1 Massed Versus Spaced Practice s0040

A standard educational practice to improve learning p0260 is to repeat target material, both with content presented in lectures as well as content presented in student workbooks and homework assignments (e.g., see **Figure 3**; [b0585] Ste-Maire et al., 2004). An extensive basic memory literature suggests that spacing repetitions of content is preferred to massing repetitions (see [b0110] Cepeda et al., 2006, for a review, though massed repetitions may confer the impression that the material is being well understood and learned; [b0045] Bjork, 1994). Experimental evaluations of the value of spacing in educational contexts have been sparser, but the results are encouraging.

In a heroic effort, [b0495] Reynolds and Glaser (1964) p0265 manipulated spacing for content in a junior high general science class for which a sequenced instructional program administered by teaching machines was being used. Students completed the programmed instruction lessons (covering 10 topics in biology) during 40-min science periods, and the experiment was conducted over the course of 4 weeks of classes. The lessons covered topics on cells, organs and systems, green plants, and so on. The experimental manipulation focused on the lesson on mitosis. This lesson was the sixth topic in a span of 10 topics covered during the 4-week period. The lesson described 11 new technical terms and required that students learn the meanings of the terms and how the terms were used to describe and understand the process of mitosis. Throughout the lesson, there were repetitions of these technical terms. In the spaced condition, this base lesson was reduced such that there were fewer repetitions of the terms, and the remaining repetitions were spaced in small review units interspersed after topic 7 (plant reproduction) and topic 8 (animal reproduction). Tests on the mitosis content were administered 2 days after (fill in the missing terms in 15 sentences) and 3 weeks after (fill in the blank, essay, and multiple-choice tests) the completion of the four-week program. It is worth mentioning that in one experiment, to ensure an equivalent delay between the most recent coverage of mitosis in both conditions (i.e., there was a review presented after topic 8 in the spaced condition), at the end of 4 weeks extra content was added to the spaced-condition program.

p0270 On the 2-day delayed test, the spaced presentation condition produced over a 50% gain in correct responding relative to the standard lesson. For testing after a 3-week delay, once again spaced presentation resulted in a 50% increase in performance for both the fill-in-the blank and the essay ('describe and illustrate the mitosis process') tests. On the multiple-choice test, for which more retrieval cues are provided, spaced presentation still produced a 33% gain in performance relative to the standard lesson. Overall then, spacing the presentation of the technical terms throughout other content produced striking benefits in learning and retention. Unfortunately, such spaced presentation may seem antithetical to the demands that most instructors face to cover increasing amounts of material in a course. Note, however, that the above study suggests that repetition within a lesson could be reduced, thereby saving time with which to space presentation of the content across other lessons.

p0275 For basic content areas (such as arithmetic, geography facts, and reading skills taught in lower grade levels) massed repeated presentations may be rarer, with spacing being the typical practice. For example, in some first-grade curricula, phonics instruction is spaced across short daily instructional periods (Seabrook et al., 2005). Even so, spacing could be more extended such that the single daily lesson is divided into three short sessions throughout the day. A small experiment involving 34 children (in two classrooms) tested this possibility. For 2 weeks, one group of first-grade children was given daily 6-min phonics lessons, and another group was given three 2-min phonics lessons distributed throughout each class day. Improvement from pre- to posttest on phonics skills was substantially better for the instruction spaced both within and across days (three 2-min sessions per day) relative to instruction spaced only across days (Seabrook et al., 2005). Accordingly, even curricula that already implement spacing might be improved with even finer grained spacing of the material. Much remains to be learned about the variety of educational content that would benefit from spaced presentations and about the time grain over which spacing is most effective, but clearly spacing is a technique that warrants serious consideration in educational practice (see also Smith and Rothkopf, 1984, for additional evidence).

2.43.4.2 Generation s0045

Another technique to increase the difficulty of encoding target material, and thereby to presumably increase elaboration, is to require the learner to generate the material rather than read the material. An abundance of experiments in the basic memory literature have reported that generation of target items produces better memory for those items than does reading. For instance, subjects remember words that they generated from word fragments better than words that they read (e.g., Jacoby, 1978; McDaniel et al., 1988). Similarly, solutions to multiplication problems are remembered better when they are generated than read (McNamara and Healy, 1995). These basic results have straightforward implications for education: Engineer instructional materials that require the student to generate the content rather than just read it. p0280

Some laboratory-based research has investigated the effects of generation with educationally relevant materials. In one experiment, some key terms in several paragraphs from an introductory psychology text were presented as word fragments (and learners generated the term) and other key terms were presented as intact words (deWinstanley and Bjork, 2004). The phrases in which all key terms were embedded were presented in red type. An example of a phrase with a fragmented key term is: the emotional or aff_ct_v_ part. Learners studied one paragraph followed by a fill in the blank test for the key term, and then studied a second paragraph followed by a fill in the blank test. For the first paragraph, generating produced better memory for the target terms than did reading. Unexpectedly, for the second paragraph no generation effect was obtained because memory for the read terms increased to levels produced by generation. This provocative result suggests that if learners observe the mnemonic benefits of generating relative to reading, then learners will spontaneously develop more effective strategies for learning the read target terms. However, the experiment was conducted at a highly selective liberal arts college, possibly limiting this positive metamemory effect of generation to high-ability learners. p0285

In another line of work, the generation task required learners to reorder a set of randomly presented sentences into a coherent text (McDaniel et al., 1986; Einstein et al., 1990; Thomas and McDaniel, in press a). In the read condition, the text was presented in normal fashion. The texts p0290 were didactic passages (e.g., describing avalanches in the Kanjenchunga Mountains) adopted from reading-training programs used in classrooms. Learners who were required to generate the texts recalled significantly more of the passage than learners who read the texts (as measured by both free recall, McDaniel et al., and cued recall for conceptual information in the text, Thomas and McDaniel). Of course, those in the generation condition also needed significantly more time to process the texts than those in the read condition. However, even when differences in processing time were statistically partialled out, the generation effect remained (in free recall; McDaniel et al.).

p0295 To successfully integrate generation into educational environments, we believe that several challenges must be surmounted. One straightforward challenge is to design generation tasks that are acceptable for the classroom. That is, requiring students to generate a coherent didactic text from randomly ordered sentences will not likely be embraced by teachers. However, there may be some limited use for this kind of generative task. In a 6th-grade class that MAM's child attended, as a learning exercise the students were given a history chronology that was scrambled, and they had to unscramble it and put it in chronological order. As well, textbooks replete with fragmented words are unlikely to become commonplace.

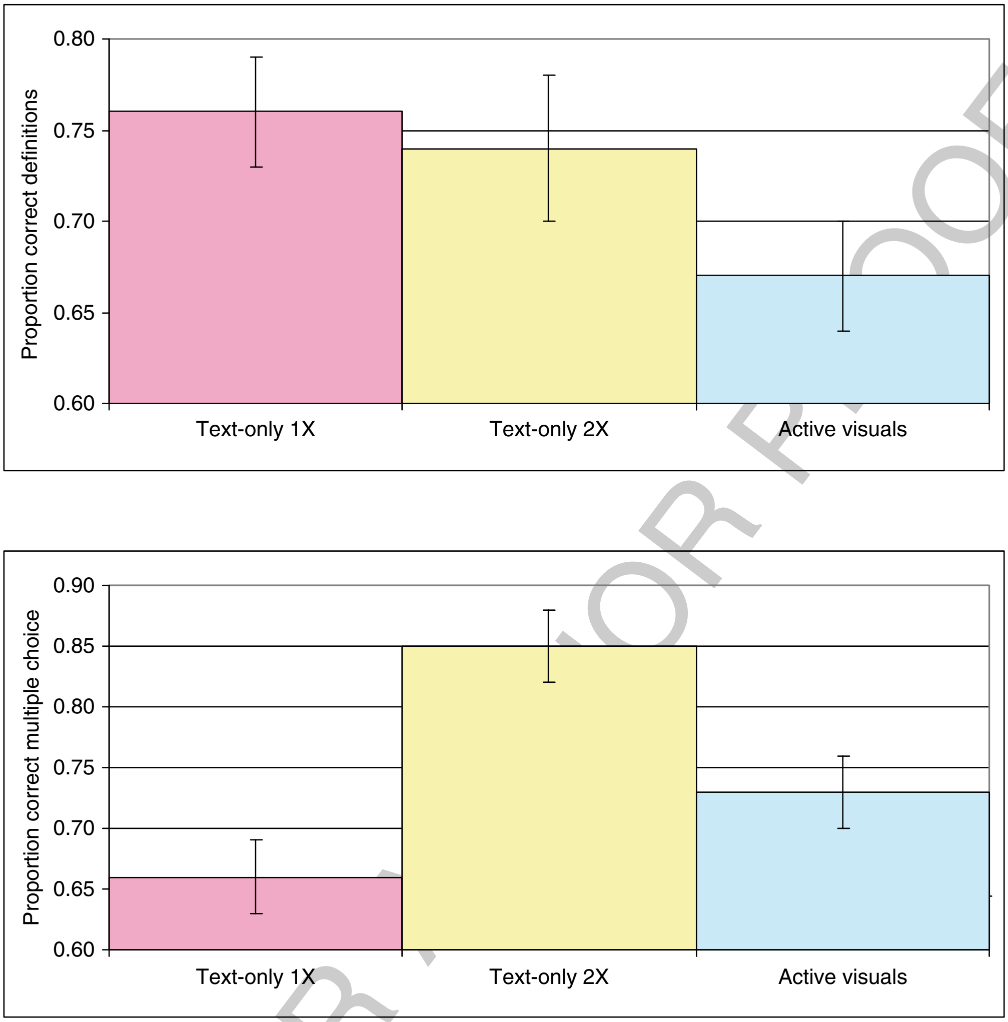
p0300 Some intriguing possibilities for implementing generation techniques in classroom settings are starting to appear, and at least one publisher is attempting to develop a prototype interactive textbook, in which interactive visuals interleaved with text require students to generate material. An even greater challenge is to gain a more complete theoretical understanding of when generation is desirable and when it is not in order to allow for effective prescription of desirable difficulty. That basic progress on this front is underscored by the disappointing effects of some classroom generation tasks (Metcalfe and Kornell, in press) and by recent findings in our laboratory (conducted with Keith Lyle, Andrea Young, and Robin Heyden) that learners given an interactive text (requiring generation of information through click and drag procedures to complete visual/spatial presentation of material) showed significantly diminished learning of definitions relative to those learners reading a comparable text (once or twice) with no visuals (see **Figure 6** for results of once-read text, twice-read text, and interactive text conditions). For multiple-choice questions on conceptual content, the interactive text produced slightly better performance than the standard text read once and worse performance than the standard text read twice (even though reading twice took slightly less time than processing the interactive version of the text). In this study, it appears that the interactive component of the text was distracting rather than facilitating for learners. Accordingly, we close this section by presenting a framework that illuminates key factors in determining the desirability of difficulty and in particular of generation.

2.43.4.3 A Contextualistic Framework of Desirable Difficulty s0050

Contextualistic accounts of memory (e.g., [b0230] Jenkins, 1979) assume that memory performance will be determined not only by the kind of processing the learner directs at the target material but also by the type of test task, the type of materials, and characteristics of the learner. These factors can be critical in determining whether introducing particular difficulties into the learning environment are desirable. We briefly present a framework that specifies in a principled way how parameters of the test task, materials, and learner characteristics will affect the desirability of difficulty (see [b0320] McDaniel and Einstein, 1989, [b0325] 2005). In concert, we will provide illustrative support for each component of the framework by presenting laboratory research using educationally relevant materials. We emphasize that this framework assumes that a necessary feature of any desirable difficulty is that the learner must be able to overcome the particular difficulty (see [b0045] Bjork, 1994). p0305

2.43.4.3.1 Test tasks and transfer-appropriate processing s0055

Basic memory work has firmly established the transfer_appropriate processing (TAP) principle, which asserts that memory performance is determined by the degree to which the learning activity stimulates processing that is appropriate for the memory test (e.g., [b0425] Morris et al., 1977; [b0350] McDaniel et al., 1978; [b0515] Roediger et al., 1989). Applied to the desirability of difficulty, the implication is that one must consider the type of processing stimulated by the particular difficulty that is embedded into the learning task in relation to the type of test administered. Specifically, we expect that types of difficult processing that simulate the sort of processing required by the criterial test will enhance learning (desirable difficulty), whereas difficulty that stimulates processing not appropriate for the test will have little or no positive p0310



f0030 **Figure 6** Definition recall (top panel) and multiple-choice test performances (bottom panel) after standard textbook presentations and interactive visually enhanced textbook presentations of biology content (from an unpublished experiment by McDaniel, Lyle, Young, and Heyden).

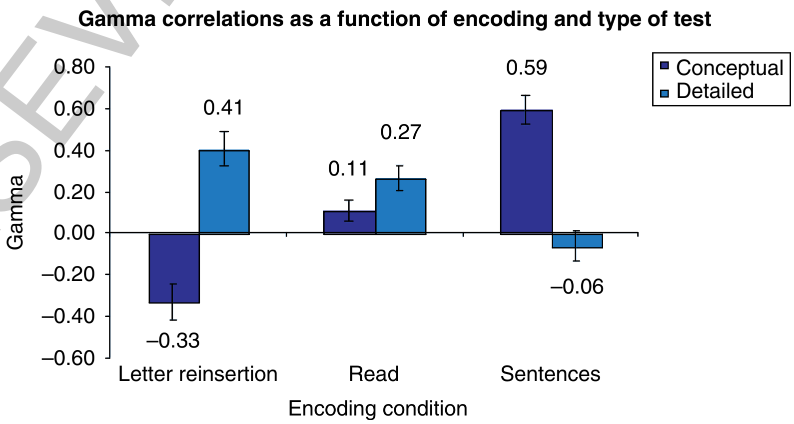
impact (a not desirable difficulty). Note that by our framework a particular type of difficulty cannot be identified as desirable in an absolute sense. Rather, a particular difficulty can be desirable when followed by one type of test and undesirable when followed by a different type of test (as we will see, the same holds for materials and individual learner characteristics).

p0315 Using generation tasks and didactic texts (e.g., discussing why leaves turn color in autumn, avalanches in the Himalayas, or spiders), Thomas and McDaniel (in press a) provided strong support for the above expectations. For each passage, two kinds of tests were prepared. One test was composed of questions focusing on details in the passage ("The walls of ice in Kanchenjunga range from ________________ feet high"), and the other test was composed of questions focusing on global thematic information (information that was presented across multiple sentences: "The downward speed of snow is much faster in Kanchenjunga than the Alps because ____________________"). Two generation (desirable difficulty) tasks were also implemented. One generation task was the sentence-reordering task described in the previous section. For the other generation task, participants had to fill in missing letters from fragmented words (letter reinsertion task). Sentence reordering has been shown to encourage relational processing of the material, and the letter reinsertion task has been shown to promote processing of details (b0370 McDaniel et al., 1994, Experiment 1).

p0320 Thomas and McDaniel (in press a) reasoned that sentence reordering would be a desirable difficulty when testing focused on thematic information but not specific details. On the other hand, letter reinsertion would be a desirable difficulty when testing focused on specific details but not thematic information. The results were even more striking than anticipated. Sentence reordering improved performance relative to a control that studied the passage without a generative task but only for the thematic test (0.63 vs. 0.49, respectively; detailed test performance was identical). In contrast, letter reinsertion improved performance on the detailed test relative to the study control (0.60 vs. 0.43, respectively) and significantly disrupted performance on the thematic test (0.30 vs. 0.49)!

p0325 Moreover, TAP effects for desirable difficulties extended to learners' metamemory accuracy (see Thomas and McDaniel, in press b, for more extensive discussion). Participants in the Thomas and McDaniel (in press a) study were asked to provide a judgment of how well they would remember information presented in each paragraph of the passage (termed a judgment of learning). Participants were informed about the type of test that would be administered and prior to the experimental passages, participants were given examples of each type of test. **Figure 7** displays the metamemory resolution (correlation of judgments of learning with actual memory performance) associated with each of the conditions. As is typically reported, metamemory resolution was modest in the study-control condition. Metamemory resolution substantially improved when the generative activity was appropriate for the test (e.g., letter reinsertion and a detailed test). But when the generative activity was inappropriate for the test, metamemory was rendered inaccurate. The correlations between predicted performance and actual performance were zero or even negative. These values indicate that in these conditions participants judged they could remember content that they did not and judged they would not remember information that they were able to remember.

These results have important implications in educational settings because metamemory is presumed to guide the control of learners' study activities (Son and Metcalf, 2000; Dunlosky et al., 2005). Thus, when a difficulty is desirable it will not only improve memory performance but also may support more effective control of subsequent study activity for the target material. However, when the difficulty is inappropriate for the test task, metamemory is abysmal and thus becomes essentially useless for effectively guiding subsequent study. Thomas and McDaniel (in press a, Experiment 2) confirmed these implications by allowing learners to restudy the passages (presented in normal format) after completing the generation task (either letter reinsertion or sentence reordering). All learners tended to spend more time studying the content that they judged they would not remember well (in line with Thiede and Dunlosky, 1999). But because learners' impressions of what needed to be studied and what did not need to be studied were inaccurate when the generation task was inappropriate for the test task (as **Table 1** shows), the additional studying failed to improve performance (relative to when no additional study was allowed). By contrast, the additional study boosted performance (relative to no additional study) when the initial generation task was appropriate for the test task. p0330



f0035 AU7 **Figure 7** Correlations between judgments of learning and memory performances as a function of study and testing conditions in Experiment 1 of Thomas and McDaniel (in press).

t0005 **Table 1** Cued recall performance with and without restudy as a function of generation and test task

Type of test		*Generation task*	
	Letter reinsertion		*Sentence sorting*
Without restudy	Conceptual	**0.30**	0.63
	Detailed	0.60	**0.43**
With restudy	Conceptual	**0.25**	0.84
	Detailed	0.81	**0.40**

AU8 The means for the inappropriate generation—test task conditions are in bold font.
Reproduced from Thomas and McDaniel (in press).

p0335 Taken together, the above theoretical insights and associated empirical results have profound implications for educational practice, both in terms of specifying the desirability of difficulty and more generally in terms of appreciating the importance of transfer-appropriate processing for students' study activities. Our initial work suggests that transfer-inappropriate study activities produce a negative cascade of effects that can penalize the learner in terms of test performance, metamemory accuracy, and control of study activities. Unfortunately educational practice does not always reflect an appreciation of the consequences of transfer-appropriate and inappropriate processing. In one situation related by a colleague, the study activity advocated in his son's ancient history class was to compare and contrast cultures in terms of political, economic, religious, scientific, and other dimensions (see McDaniel, 2007). One would expect this study activity to produce integrative, thematic processing, and thus many educators might embrace its use. Yet the instructor gave multiple-choice tests to the class, which focused on specific facts. To the extent that this supposedly good study scheme produced processing inappropriate for the test, it harmed students' memory and metacomprehension for the tested material rather than enhancing it.

s0060 ### 2.43.4.3.2 Material-appropriate processing

p0340 A second contextualistic factor that influences the desirability of difficulty is the to-be-learned material. With regard to texts, it is clear that there is variation across texts in terms of the kinds of processing afforded by the text. For instance, texts for which readers' prior knowledge about conventional frames and scripts (knowledge about structures of episodes and causal structures that relate events, as well as knowledge of the canonical structures of particular text forms) can be activated in the service of comprehension to allow readers to readily organize the content (van Dijk and Kintsch, 1983; Trabasso and van den Broek, 1985; Fletcher and Bloom, 1988). In contrast, texts that do not have such organizational properties appear to force readers to focus on individual propositions to try to gain some understanding of the content (see McDaniel and Einstein, 1989, for details). The desirability of a particular difficulty will be a function of the overlap between the type of processing encouraged by the material (e.g., the text) and the type of processing stimulated by the difficulty task (e.g., generation).

Evidence for the above principle has been gleaned p0345 using the generation tasks discussed in the previous section. Because the sentence-reordering task stimulates organization of the ideas within the text, this generation task is desirable for a text that encourages focus on individual propositions (a didactic text for which the learner has little prior knowledge); however, this processing is redundant for a text that already encourages organization (e.g., a fairy tale) and thus is not desirable for this kind of material. Conversely, because the letter insertion generation task presumably stimulates focus on individual concepts and propositions, this task is desirable for a text that fosters organization, but it is not desirable for a text that encourages focus on individual propositions. These predicted patterns have been reported using free recall as the criterial test (a test for which both elaboration of individual elements and organization of the elements produces optimal performance) (McDaniel et al., 1986; Einstein et al., 1990; see McDaniel and Einstein, 2005, for a summary). The striking feature of these results is that there is no significant benefit to recall (and sometimes not even any nominal benefit; McDaniel et al., Experiment 1) when the particular generation task is redundant with the processing encouraged by the text itself, despite five- to eightfold increases in the time needed to comprehend the text.

p0350 The above results are partially limited in their direct generalization to education because fairy tales were used for some of the materials. At a general level, however, the essential lesson here is that any particular generation (or difficulty) task cannot be identified as desirable *per se*; depending on the context, incorporating a difficulty could be useless and inefficient. As applied to education, this point cautions against sweeping recommendations concerning introducing particular sources of difficulty into instruction. Instead, determination of desirable difficulty will necessitate a careful analysis of the processing stimulated by the type of difficulty and its appropriateness for the criterial test and the materials being learned. For instance, even within a text genre, the rated interest of the text seems to modify the processing invited by the text and thus the desirability of a particular difficulty (generation) task ([b0375]McDaniel et al., 2000).

s0065 *2.43.4.3.3 Differences in learners*

p0355 Even the foregoing analysis is incomplete because it does not acknowledge a third important contextual factor, individual differences in learners. Learner characteristics (comprehension ability) have also been shown to modulate the desirability of a particular difficulty manipulation. For example, learners who are high in structure-building ability (those who readily form coherent, organized representations of the content of text, [b0170]Gernsbacher, 1990) may not benefit a from difficult task that stimulates organization (sentence reordering), whereas low-ability structure builders (who do not ordinarily form well-organized representations) do show improved recall when such difficulty (sentence reordering) is introduced ([b0380]McDaniel et al., 2002).

p0360 In another line of work, [b0405]McNamara and Kinstch (1996) found that increasing the difficulty of text by reducing its coherence improved criterial performance (relative to the more coherent version) for learners high in background knowledge but not for learners with little prior knowledge of the content. These initial studies suggest that further investigation of how individual learner characteristics influence the desirability of difficulty could translate into fruitful application to education. In this vein, we turn now to a consideration of individual differences and their interaction with study adjuncts that have received more attention in the educational literature.

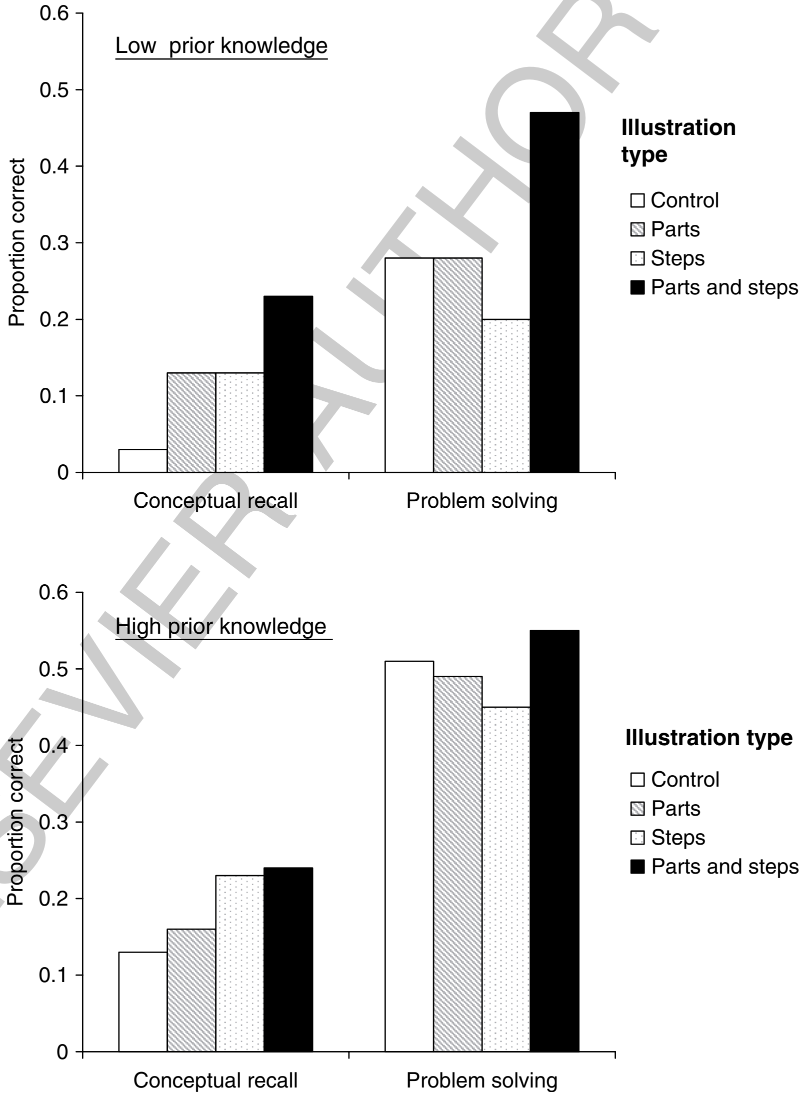
2.43.5 Comprehension s0070

2.43.5.1 Individual Differences s0075

As mentioned in previous sections, individual differences in reading comprehension moderate the benefits of various study methods (though individual differences have largely been ignored in basic laboratory work; [b0430]Naveh-Benjamin, 1990). One conceptualization of comprehension based on laboratory materials (narratives) that we have found fruitful is [b0170]Gernsbacher's (1990) Structure Building Framework. In this framework, it is suggested that readers build a mental representation of the text. The representation is built on a foundation of the initial, important information encountered in the text. As new information is encountered, it is either incorporated into the existing framework, or if it is not conceptually related to the existing framework, a new substructure is built out of the new information. It is theorized that poor comprehenders are not able to inhibit irrelevant information. Further, they have difficulty incorporating information into the existing structure. This results in the poor reader shifting multiple times and constructing many more substructures than a good comprehender. A good comprehender, however, is able to inhibit the irrelevant information and build a coherent, well-organized mental representation of the text. p0365

We have examined several different adjuncts (study methods) to try to help poor comprehenders build better representations of the text. One long-standing method used both by researchers and educators is embedded questions, questions placed throughout the text targeting specific content, which have been shown to be generally beneficial ([b0200]Hamilton, 1985). We showed that answering embedded questions improved performance on both multiple-choice and short-answer questions requiring application of target material for low-ability but not for high-ability comprehenders ([b0090]Callender and McDaniel, 2007). Further, this benefit of embedded questions was significant over a read-twice control (which equated the amount of time those who only read and those who answered the questions spent with the text). By targeting specific points in the text, it appears that embedded questions provide low comprehenders with an anchor around which students can build their representation (cf. [b0300]Mayer, 2003). This adjunct helps to improve the mental representation of poor comprehenders more than simply rereading a text. Also, as mentioned earlier, low comprehenders (but not high comprehenders) showed learning benefits (relative to the read-twice p0370 control) when why questions to prompt explanatory elaboration were inserted into the text.

p0375 Other research investigating study adjuncts has also revealed the importance of attending to individual differences in comprehension ([b0305]Mayer and Gallini, 1990; [b0395]McNamara, 2004). One type of individual difference that affects comprehension processes is the amount of prior knowledge one has for the text content. [b0305]Mayer and Gallini (1990) showed that some adjuncts, like illustrations, improve performance of low-knowledge readers but not high-knowledge readers. Using three different texts to establish generality of the benefits of illustrations, the authors showed that in specific instances, illustrations can improve test performance. When an explanative text is used (that is, a text that contains cause and effect) with illustrations that convey both parts of the system as well as the function of the parts, the illustrations can improve performance on questions requiring application of knowledge. Illustrations do not improve performance for fact-based questions or questions that require verbatim memory for the text. However, these findings only hold for low-knowledge readers. The illustrations bring the low-knowledge readers close to the level of high-knowledge readers on conceptually based questions, but high-knowledge readers do not benefit from the illustrations (although their performance is not harmed by the illustrations, either; see **Figure 8**).



f0040 **Figure 8** Recall and problem solving as a function of illustration type and prior knowledge in Experiment 1 of Mayer RE and Gallini JK (1990) When is an illustration worth ten thousand words? *J. Educat. Psychol.* 82: 715–726.

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p0380 Individual differences in knowledge level have also been connected with moderating benefits of comprehension training ([b0395]McNamara, 2004). McNamara developed a comprehension training system called Self-Explanation Reading Training (SERT). The basis of SERT is that those who explain the text are able to build better mental representations of the text. The goal of SERT is to improve the self-explanations of readers to further enhance the benefits of self-explanation. Specific strategies used by SERT include comprehension monitoring, paraphrasing, making bridging inferences, elaborating, using logic, and predicting (see **Table 2** for examples). These strategies enabled low-knowledge readers to use general, world knowledge or logic to compensate for their lack of knowledge specific to the domain being studied. When answering text-based questions, training significantly improved performance of low-knowledge readers, but not of high-knowledge readers. Questions requiring inferencing were not influenced by training; rather, only prior knowledge affected performance. Thus, again we see that question type and prior knowledge influence performance on final tests, although, in this case, individual differences in prior knowledge interacted with training on text-base questions (rather than conceptually based questions of [b0305]Mayer and Gallini, 1990). Most striking is that the low-knowledge readers' performance doubled with the training. All three adjuncts addressed in this discussion of individual differences not only improved performance of the low-comprehension or low-knowledge readers, but improved performance greatly: Performance increased either to the same level as the high-ability/-knowledge readers or doubled with the use of the method.

In sum, comprehension (and memory) of educational materials can be improved by study adjuncts. Importantly, though, both educators and researchers should be cognizant that individual differences may interact with various study adjunct and text characteristics (such as coherence or genre) such that benefits will not extend to all students. In this regard, knowledge and reading ability have so far been identified as important individual differences. p0385

2.43.5.2 The Importance of Text Coherence s0080

One central process in text comprehension is the construction of a structured representation of the text. A cognitive theory of this process has important implications for improving comprehension in educational situations. We first sketch this theory and then examine research investigating the educational application of the theory. In [b0245]Kintsch and van Dijk's (1978) theory, the reader builds a structured representation p0390

t0010 **Table 2** Examples of students' self explanation strategies

Strategy	*Self-explanation*
Comprehension monitoring	Example 1: "I don't remember what DNA stands for." "So I guess daughter cells are part of a larger cell or came from a larger cell – I don't know."
Paraphrase	Example 1: "So each daughter cell will receive a duplicate copy of the same strand of DNA from the parent cell." Example 2: "Ok through this process of mitosis all the genetic information belongs in the DNA of the parent cell and that is transferred over to the daughter cell."
Bridging inference	Example 1: "So mitosis – the first stage of cell division where each set of chromosomes goes to each daughter cell will contain DNA." Example 2: "So, yeah, so all the genetic information is in the chromosomes and each cell gets a complete set, so that's mitosis – when each cell has just as much DNA as the first mother cell – main cell – parent cell."
Elaboration	Example 1: "Ok so there's the daughter cell and then there's a parent cell – mitosis it has to do with genetic information so when I'm thinking of cell division I'm thinking of maybe how a baby is made and how it's developing." Example 2: "So by mitosis it guarantees that the chromosomes will get passed on so that the traits or whatever will be able to live on or whatever."
Using logic	Example 1: "Ok what they're saying is that mitosis will make sure that an equal amounts of genetic information will go to each of the cells – equal amount will go to each daughter cell that way. They will develop basically the same – multiply the same." Example 2: "Ok, so the genetic information that must be the chromosomes because the chromosomes are going into each of the cells. And that is made up of the DNA. So a part of . . . a part of each of the . . . a part of genetic information which is the DNA goes into each of the two cells that come out of this."
Prediction	Example 1: "Ok this is the separation of the cell – the DNA – the next one should be the RNA." Example 2: "So that's the first stage, now they'll give the second one."

Note. Sentence: "Mitosis guarantees that all the genetic information in the nuclear DNA of the parent cell will go to each daughter cell."
Reproduced from McNamara DS (2004) SERT: Self-explanation reading training. *Discourse Process.* 38: 1–30.

of the text by attempting to establish connections among the propositions (ideas) expressed in the text. These connections are based on referential overlap: Formally, referential overlap is present when propositions share at least one identical concept. Working memory plays a fundamental role here, because during reading several propositions from previously read portions of the passage are held in mind while reading the next chunk of text (e.g., a sentence). The next chunk of text is integrated into the developing text representation if any one of the propositions in working memory has referential overlap with the new propositions (from the incoming chunk of text). If referential overlap cannot be established between the propositions in working memory and the incoming propositions, then the reader must search the text representation in long-term memory to find a proposition that does overlap with incoming content. This search of long-term memory is termed a reinstatement search, and such searches significantly slow comprehension (Kintsch and van Dijk, 1978).

p0395 An even more serious challenge to comprehension is when the reinstatement search fails (these are termed text breaks). At this point, standard coherence processes cannot continue, and an inference must be generated to connect the incoming propositions (new sentence) with propositions in working memory. The problem is that readers may not try to generate a linking inference (see for example, Noordman et al., 1992) or readers may attempt to generate a linking inference but fail. In either case, the text representation becomes less coherent and comprehension (and memory) accordingly suffer (see Britton et al., 1990). Critically with regard to education, a survey of social science texts showed that typical textbooks tended to have numerous text breaks (Beck et al., 1989), and perhaps as a consequence, students' ability to comprehend textbooks is hampered (Snow, 2002). The intriguing implication of the theory, however, is that students' comprehension could be improved if the text breaks in the textbooks were eliminated.

p0400 Britton and Gulgoz (1991) conducted a study to test this implication. Based on the theory just described, they revised a section of a chapter from a college history text. For every text break in the passage, they inserted material to ensure referential overlap and to make explicit important inferences so that text coherence could be established (without inference generation or costly reinstatement searches). This theory-based revision was contrasted against a revision prepared by a writing expert, who attempted to produce the best possible revision that he could. In addition, a readability revision was prepared that lowered the difficulty of the original by two grade levels. In a first experiment, college students read one of these three revisions or the original passage at their own pace, and then were given free recall, a fact test, and an inference test. All students were forewarned about these tests. Students given the theory-based and the expert-based revisions performed comparably on the comprehension and memory tests and significantly better than did the students given the readability revision or the original passage.

In a second experiment, modeling analyses were used to assess the network structure of the mental representations formed by students after reading the theory-based revision, expert-based revision, or the original passage. Students' mental networks after reading either of these two revisions (but not after reading the original) were correlated with the textbook author's knowledge network of that content. Thus, the revisions enabled to the students to better extract a more expert-like representation of the content than the original version. p0405

Two important implications follow from these results. First, principled revisions can substantially improve the didactic value of at least some textbooks. Second, and most pertinent for this chapter's theme, a cognitive model of text comprehension can be successfully applied to diagnose problems in educational texts and prescribe repairs to the text that substantially improve students' representation and memory of the text. Further, as Britton and Gulgoz (1991) note, this theory-guided revision is preferred over expert-guided revision because it provides concrete, well-operationalized guidelines to repair educational text and it is easy to implement. With approximately 2 h of training on the Kintsch and van Dijk (1978) model, a technician can begin to effectively revise textbook material. p0410

2.43.6 Using Testing to Enhance Learning s0085

Generally, educators use testing to assess student learning. However, basic memory research has shown that testing itself promotes learning and retention, and that often the mnemonic benefits of testing are superior to additional study of the target material (e.g., Hogan and Kintsch, 1971; see Roediger and Karpicke, 2006b, for an extensive review). These p0415 findings are theoretically important because they imply that processes involved in retrieval are potent modifiers of memory, that is, that the testing effect is not merely a re-exposure effect (Bjork, 1975; McDaniel and Masson, 1985; Carpenter and DeLosh, 2006). The implication for education is striking: Instead of using testing solely as an evaluation procedure, testing (i.e., requiring retrieval of to-be-learned material) could be exploited to enhance learning and retention. Sporadically, educational psychologists have noted this possibility and provided empirical support for the testing effect (Spitzer, 1939; Glover, 1989), but it has largely been ignored as evidenced by the title of Glover's (1989) paper "The 'testing' phenomenon: Not gone but nearly forgotten."

p0420 Recent research in the laboratory that has attempted to simulate classroom contexts and research conducted in an actual course has reinforced the value of using tests (quizzes) to enhance learning and retention. We briefly describe two examples here, but note these are not exhaustive (e.g., see Roediger and Karpicke, 2006a; Karpicke, 2007; Kang et al., in press). In the laboratory, Butler and Roediger (2007; see also McDaniel et al., in press b) presented students art history lectures that were commercially available as continuing education DVD courses. After students viewed a lecture, they were either given a short-answer test on some of the target facts, a multiple-choice test on the facts, or focused restudy of the facts. Thirty days after the lecture students were given a final criterial test of short-answer questions (e.g., 'What aspect of Morisot's art could be used to date her paintings?'). Performance on the final test was better for target facts that had been presented for restudy or presented on the multiple-choice quiz relative to control facts (those not restudied or quizzed). Further (and significant) gains in final performance were evident for facts that had appeared on the initial short-answer quiz. Assuming that the short-answer quiz required more retrieval processing than the multiple-choice quiz (i.e., more reliance on recall than recognition; cf. McDaniel and Masson, 1985), these results support the idea that requiring learners to retrieve target information enhances learning even more than additional study.

p0425 Parallel findings have been reported in an experiment conducted in a college biopsychology course (McDaniel et al., in press a). For each assigned textbook chapter in the course, some target facts were presented for restudy, some were quizzed with a multiple-choice test, some were quizzed with a short-answer test, and some facts were neither presented for restudy nor quizzed. The quizzes (and restudy presentation) were presented on the course web site and corrective feedback was given for the quizzes. Students were able to take the quizzes anytime they wanted prior to unit exams, which were composed of multiple-choice questions (administered every 3 weeks). On the unit test, unlike previous work (e.g., Butler and Roediger, 2007; Kang et al., in press), the stems for the unit questions were changed from those appearing on the quizzes. For example, if the quiz used the stem, 'All preganglionic axons, whether sympathetic or parasympathetic, release __________ as a transmitter,' then the item would appear on the unit test as, 'All __________ axons, whether sympathetic or parasympathetic, release acetylcholine as a neurotransmitter.' Accordingly, this experiment was sensitive to effects of testing on learning of integrated facts or concepts, rather than learning of a particular answer.

Performance on the unit tests showed that items that were not previously exposed (i.e., not seen in restudy, multiple-choice, or short-answer quizzing) fared as well as items that were exposed for restudy. Multiple-choice quizzing produced a slight but significant improvement on the unit test relative to performance on the not previously exposed items. Short-answer quizzes (with feedback) produced the largest increase in performance on the unit exam relative to the non-preexposed items and better performance than for items quizzed with multiple choice. On a cumulative final multiple-choice test administered approximately 5 weeks after the last unit exam (for which the experimental conditions were in effect), the significant benefit of initial short-answer quizzes persisted, while the multiple-choice format benefit did not remain significant. However, it may be that with repeated quizzing that even multiple-choice quizzing would be more mnemonically potent. p0430

Thus, under the variable conditions found in a course setting, such as student differences in completing assignments, amount of study, motivation, and various delays between taking quizzes and exams (when students self-schedule the quizzes), testing (especially testing that challenges retrieval, such as recall tests) enhances learning and retention. These findings are even more impressive in that transfer was evident across different question frames from the quizzes to the examinations. The p0435 strong implication is that, at least in courses that are heavily fact-based, using testing to enhance learning should be seriously considered.

s0090 2.43.7 Summary

p0440 Over the years, a number of researchers have advocated application of cognitive research to improve educational practice (e.g., [b0525] Rothkopf and Bisbicos, 1967; [b0215] Hudgins, 1975; [b0295] Mayer, 1987; [b0430] Naveh-Benjamin, 1990; [b0045] Bjork, 1994; [b0300] Mayer, 2003, to name a few). In this chapter, we have attempted to translate established principles from the memory and comprehension literature into fairly specific implications and techniques that could be implemented in educational settings. Based on current basic research, we were able to identify an array of techniques, including stimulating explanative elaborations, mnemonic use of imagery, organizational devices, including desirable difficulties, and repairs to text (for example, increasing the coherence of the text) to improve learning and retention (and certainly, this is not an exhaustive list). A prominent objective here was to evaluate the potency of these candidate techniques from experimental investigations that approximated the materials, test tasks, and other contextual variables present in educational settings. The evidence was quite encouraging in this regard, and we believe it provides the foundation for effective implementation into educational practice.

p0445 In support of this claim, we close with a brief description of recently reported work that has combined several techniques discussed herein into a computer-based learning program implemented in a game format to assist students' vocabulary learning in a challenging inner city school setting (Metcalfe and Kornell, in press; Metcalfe et al., in press). The computer-based program implemented some of the principles reviewed in this chapter such as spaced practice, generation, and testing to enhance learning. Grade 6 children in an inner-city public middle school in New York City's South Bronx either were assisted with learning necessary vocabulary by the computer-based program, or they attempted to learn the vocabulary in a self-study condition. After 7 weeks, test performance on the vocabulary learned in the computer condition was over 400% of that observed for vocabulary learned by self-study. We think that these impressive results strongly compel continued efforts to translate basic work in memory and cognition into effective educational applications.

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Keywords: advanced organizers; desirable difficulties; embedded questions; elaboration; imagery; individual differences; keyword method; outlining; test-enhanced learning

Abstract
Based on findings in basic memory and comprehension research, we note implications for enhancing acquisition of factual information. For each implication, we identify techniques that could be implemented to assist students' acquisition of material in fact-laden courses. We evaluate the potential effectiveness of those techniques for education practice by reviewing translational research that uses educationally relevant materials and test tasks. Specifically, extending basic memory research, we discuss implications from findings on rote repetition (rereading text), elaboration (elaborative interrogation, advanced organizers, and imagery mnemonics), and desirable difficulty (creating interference, spacing, and generation). We suggest a contextualistic framework for understanding when difficulty is and is not desirable, including considerations of transfer-appropriate processing, material-appropriate processing, and individual learner differences. Building on basic research in comprehensive, we identify study methods that are sensitive to individual differences, techniques to improve successful inferencing, and principled text revisions to enhance comprehension. The final section touches on the mnemonic benefits of retrieval and discusses recent research demonstrating the value of using repeated testing to enhance learning (i.e., to improve performance on final criterial tests). The research discussed in this chapter supports the efforts to apply basic findings in memory and cognition to enhance educational practice.