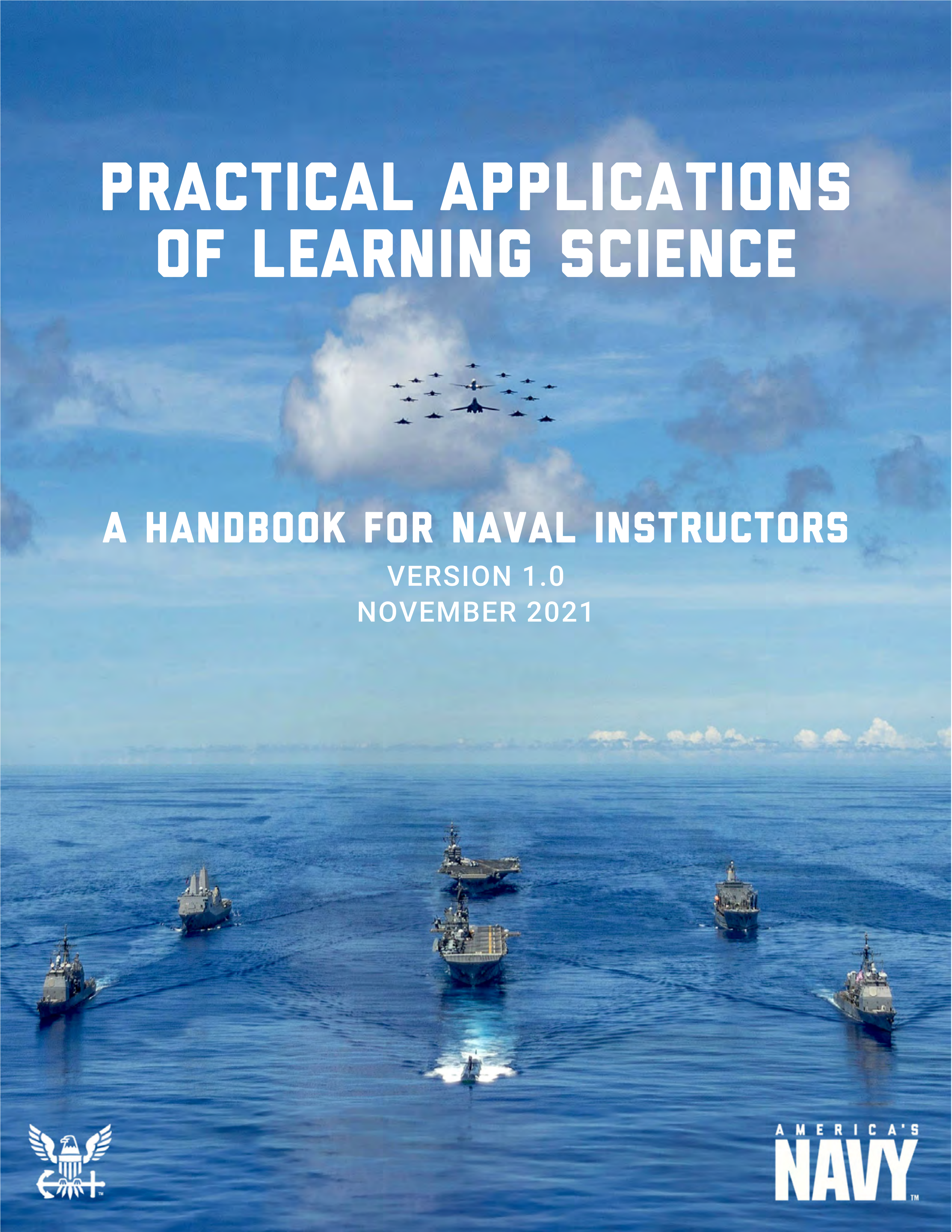
PRACTICAL APPLICATIONS OF LEARNING SCIENCE

A HANDBOOK FOR NAVAL INSTRUCTORS

VERSION 1.0

NOVEMBER 2021



AMERICA'S NAVY

IN NO OTHER PROFESSION ARE THE PENALTIES FOR EMPLOYING UNTRAINED PERSONNEL SO APPALLING OR SO IRREVOCABLE AS IN THE MILITARY.

–DOUGLAS MACARTHUR, 1933

TABLE OF CONTENTS

INTRODUCTION

Medicine and engineering, as professional disciplines, adopted an approach to research and development founded on theory building paired with experimental validation. The products of medical research are seen in pharmacies, clinics, and hospitals as well as research laboratories and medical schools. The same can be said for engineering. All the tools and processes used in transportation, telecommunications, energy production, computing, agriculture, manufacturing, and construction are the result of scientific research followed by engineering and product development.

In contrast, instructional strategies used in the field of education and training are based on ideology, intuition, or preference; often couched under the term “best practices.” At best, unproven instructional strategies are simply hypotheses waiting for scientific validation through experimental studies. At worst, they are ineffective, or even counterproductive, while producing the illusion of learning.

1. Retrieval Practice

The act of recalling information from long-term memory is what makes it more memorable in the future. Instructors should use a number of low-stakes quizzes (oral and written) throughout their lessons to encourage students to retrieve information from memory.

2. Spaced Practice

Distributing study time over several short sessions produces better long-term memory than a single, long study session. Rather than cramming four hours the night before a test, students should study for one hour on each of the four days leading up to the test.

3. Interleaving

Switching between related problem types while studying, and varying the conditions of practice during training, improves transfer of knowledge and skills. Instructors should include old and new problem types in homework; trainees should rotate through several stations.

The solution to this problem is not yet another innovative approach to teaching and learning, but rather to insist that all solutions be developed and evaluated using experimental research similar to other professional disciplines.

From a thorough a review of the scientific literature on teaching and learning, six psychological principles were identified that are strongly recommended as the foundation for education and training in the United States Navy. To satisfy the requirements for inclusion in this handbook, each principle needed to meet the following criteria:

- There is strong consensus within the learning science community, based on the results of experimental research studies, that its effects on acquisition, long-term retention, and transfer are consistently positive and significant.
- It is universally effective, independent of learner characteristics, subject matter, and instructional modality.
- It can be readily measured, leading to improved observations with feedback in new instructor training programs.
- It is easy to implement, even by a novice instructor.
- It is inexpensive to implement.
- It is not dependent upon technology, but it can be implemented through technology.

4. Dual Coding

Because people process information through two separate channels (verbal and visual), combining words with pictures leads to better learning than from words alone. Images on a screen should be described by an instructor with spoken, rather than written, words.

5. Concrete Examples

Using specific, real-world examples to explain abstract ideas makes those ideas easier to understand, remember, and use. Instructors should introduce concepts in abstract form first and then provide a range of concrete examples to highlight the essential features.

6. Elaboration

The process of relating new information to material already known, as well as organizing and expanding on ideas, makes information more memorable. Instructors should ask their students to provide answers for question that start with *How*, *Why*, and *What if*.

Each of these principles is defined and described in this handbook using representative experimental research studies. Actionable recommendations for instructors and students on how to implement the principles in classrooms and other training environments are also be provided.

1. RETRIEVAL PRACTICE

The act of recalling information from long-term memory is what makes it more memorable in the future.

Application example: An instructor uses frequent low-stakes quizzes (oral and written) throughout his lessons to encourage students to actively recall information from memory.

In education and training settings, learning and testing are often viewed as two separate activities. A well-established finding from psychological science is that the act of retrieving information during a test strengthens memory for the tested material (Karpicke, 2017; Roediger et al., 2011). Accordingly, instructors should think of testing as a memory-strengthening activity. And since many students are extrinsically motivated by test scores, it may actually be one of the most powerful strategies to support student learning an instructor has in their repertoire.

Retrieval practice, in the form of self-tests, is also a very effective strategy for students to use while studying. Self-tests are far more effective for building memory strength than common study methods that are passive, such as rereading highlighted passages of text or listening to an instructor repeat previously taught material during a review session (Ariel & Karpicke, 2018). In fact, research consistently demonstrates that students recall approximately 50% more information after they test themselves compared to when they study using other methods that do not include self-testing (Dunlosky et al., 2013; Karpicke & Roediger, 2008).

Recommendations for Instructors

1. Make retrieval practice a normal part of instruction, not a stressful event that determines a student's grade, by using low- or no-stakes quizzes throughout a lesson. (You can call a quiz at the beginning of a class a "review" to make it less stressful to students.)

2. Use fill-in-the-blank questions to promote recall rather than multiple choice questions that only require recognition (Glover, 1989). Even though initial performance is not as high with recall tests as it is with recognition tests, long-term retention will be much better (Carpenter & DeLosh, 2006).

3. Use closed-book tests that require retrieval practice rather than open-book tests that do not (Agarwal et al., 2008). Searching for the correct answers and copying them down, as in open book tests, does not increase memory strength.

4. Start lessons with a short, student-led review session. The student(s) leading the session benefit from selecting, organizing, and presenting the information; the other students benefit by strengthening memories through the retrieval practice that occurs during the session (Stavnezer & Lom, 2019).

5. Encourage your students to frequently test themselves during self-regulated study sessions to determine what they know and don't know. Testing requires retrieval practice, which is beneficial in and of itself, and the result of each test will help them to understand how to allocate their remaining study time most effectively (Ariel & Karpicke, 2018; Broeren et al., 2021).

Recommendations for Students

1. Retrieving information through self-testing is what strengthens it in memory. Highlighting and rereading information is relatively ineffective since no retrieval is required. Using highlighting to identify important information *can* be useful if you practice retrieving the information, with quizzes, several times (Dunlosky et al., 2013).

2. Quiz yourself frequently while you're studying. Put away your books and notes and then write down everything you know. Compare what you've written with your class materials to make sure you're recalling everything correctly.

3. Take as many practice tests as you can. If there aren't any available, make your own tests and trade them with your fellow students.

4. Use flashcards to memorize important facts. Don't simply read the front of the card and then the back, though; read what's on the front and then try to *recall* what's on the back. Once you have an answer in mind, or you've given up, turn the card over to read the correct response.

5. Also, when you use flashcards, don't drop a card the first time you recall the answer correctly. Keep it in the study pile until you recall the correct answer at least three times—although five or six is better (Driskell et al., 1992; Kornell & Bjork, 2008a).

2. SPACED PRACTICE

Distributing study time over several short sessions produces better long-term memory than a single, long study session.

Application example: A student budgets four hours of study time to prepare for an important test. Rather than cramming for four hours the night before the test, they decide to study for one hour on each of the four days leading up to the test.

The effect that spacing out practice has on long-term retention of knowledge and skills has been systematically investigated by scientists for well over a century (Ebbinghaus, 1885). The results are clear and consistent: Spacing out practice over time is far more effective for building long-term memory than the opposite strategy of combining all practice activities into a single session (called "massed practice," or more commonly, "cramming") (Carpenter et al. 2012).

Very simply, if a student has four hours to devote to learning some material, their time would be far better spent studying for one hour on four different days than for four hours on one day. And during a single study session, they should break up the material being studied into chunks and then review (using retrieval practice) each chunk several times separated by as much time as possible, rather than going over each chunk several times in a row.

Note: Spaced practice only refers to the schedule itself, not to what the student does during the practice session. For example, spaced rereading is far less effective than spaced retrieval practice.

Recommendations for Instructors

1. Conduct a review session at the beginning of each class period to provide students the opportunity to retrieve previously learned material. This will strengthen long-term memory through spaced practice and ensure that students have the prerequisite knowledge for the current lesson.

2. Break up long lessons into several smaller lessons and distribute them over several days. For example, teach your students foundational concepts on the first day. On subsequent days, ask them to retrieve that information during a review session in preparation for learning new information that builds on it.

3. Include a break in the middle of a lesson to refer back to information covered in previous lessons by asking questions about it and then asking students to make connections to the current lesson. (Don't simply retell them what you covered previously.) This strategy takes advantage of retrieval practice, spaced review, and other strategies covered later in this report including interleaving and elaboration.

4. Conduct several cumulative review sessions to efficiently practice material learned at different times in the course. This supports retrieval practice and spaced review and it supports the process of elaboration by making connections between several topics.

5. Develop homework sets that include new and old material. A rule of thumb is that two-thirds of the problems should come from the current unit and one-third should come from previous units. (It's just as important to retain what has been learned as it is to learn something new.)

Recommendations for Students

1. Plan for tests early and set aside time to study a little bit during several sessions rather than all at once the night before. Four, 30-minute study sessions spread over a week is much more effective than one two-hour study session. Another benefit of this strategy is that you won't feel the pressure of a marathon study session on the night before a big test.

2. Spend a few minutes reviewing what you learned in class each day. Don't do this immediately after class, though, wait at least a few hours. Quiz yourself rather than simply rereading the material. This will help to reinforce the information in memory, reducing the amount of time you will need to spend studying (or relearning) the information later.

3. Be sure to include information from older lessons in your review sessions. It helps if you create review sheets with questions on the front and answers on the back. Treat them like quizzes. This will help to make sure you are *retrieving* information from memory rather than simply rereading what you wrote.

4. If you believe that writing down facts helps you to learn them, here's how to do it more effectively: Don't write out a fact you want to remember over and over—it won't build memory strength. Write them out once, study some other material, then on a blank piece of paper, write them down again *from memory*. Repeat this as many times as you like, spaced out over time.

5. Increasing the time between practice sessions—called *expanding retrieval review*—is the most efficient approach to building long-term memory (Cull et al., 1996).

EVIDENCE FOR PRACTICE STRATEGIES

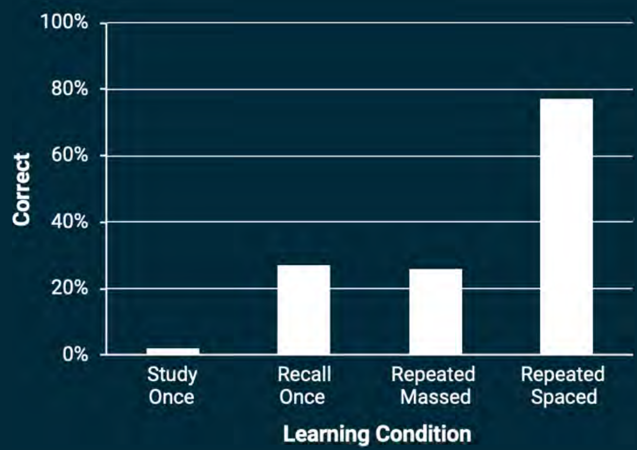
Karpicke and Bauernschmidt (2011) conducted an experiment to determine the differential effects of "studying" foreign vocabulary words by reading them side-by-side (e.g., malkia – queen), and "recalling" them—using retrieval practice—by typing in the English translations of a Swahili words presented to them (e.g., malkia – _____). They also combined these two approaches with massed and spaced practice to see if the effects would be amplified. Students were randomly assigned to four groups as follows:

Group 1: Students studied the words one time without trying to recall them—they simply read each of the Swahili-English word pairs once.

Group 2: In the first round, students studied all the words in the list once, like Group 1. In the second round, they tried to recall all the English words by typing in the translation for each Swahili word shown to them. The first time a translation was recalled correctly, it was dropped. The students repeated recalling all of the words remaining in the list until none were left.

Group 3: Like Group 2, students studied the word list once and then recalled them all in the second round. The first time an English translation was recalled correctly, however, it was immediately presented for recall three more times in a row (massed practice).

Group 4: Like Group 3, students studied the word list once and then recalled them all in the second round. Once they recalled an English translation correctly, they were asked to recall and type it in three more times. Rather than presenting the prompt immediately, however, the three recall trials were spaced throughout the study session (spaced practice).



Although it may not be surprising to see that test performance of Group 1—who only read through the list of words once—was so low, the reader should reflect on the fact that much of what is presented to students in lectures and through readings is only experienced by them once, passively. Presenting information *isn't* teaching if an instructor doesn't encourage their students to process information deeply.

Less intuitive is the fact that repeated massed practice of information (Group 3) was no more effective in strengthening memory than recalling information one time (Group 2). It's as though the first attempt to recall the information produces all of the benefit and further, *immediate* recall attempts add no value.

Finally, and most importantly, the power of spaced practice is revealed by comparing the test results of Group 3 and Group 4. Even though both groups actively recalled the information the same number of times, the *schedule* of their recall attempts made a significant difference. More than *three times* the number of items were correctly recalled during the test by those who studied using spaced practice than those who studied using massed practice.

OPTIMAL PRACTICE STRATEGIES

Development of basic knowledge and skills to the necessary levels of automatic and errorless performance requires a great deal of drill and practice…drill and practice activities should not be slighted as "low level." Carried out properly, they appear to be just as essential to complex and creative intellectual performance as they are to the performance of a virtuoso violinist (Brophy,1986, p. 1076).

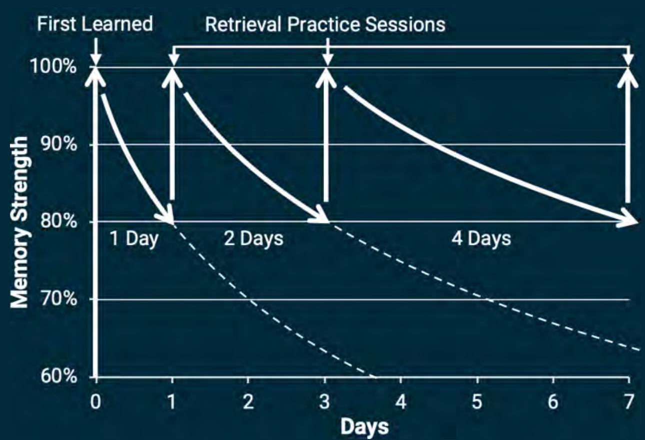
Fortunately, there is an extensive body of scientific literature that describes strategies that promote fluency—"the fluid combination of accuracy plus speed that characterizes competent performance" (Binder, 1996, p. 164). One such approach that combines retrieval practice, spaced practice, and interleaving is called "incremental rehearsal" (Tucker & Burns, 2016). It is specifically designed for the *initial acquisition* of basic knowledge and skills.

Lessons are typically comprised of 8 to 12 items and are sequenced *within* a practice session as follows:

U_i K_1 U_1 K_1 K_2 U_2 K_1 K_2 K_3 U_3 K_1 K_2 K_3 K_4 U_4…

Where U sub-i is the initial presentation (using retrieval practice) of the unknown item, U sub-n is the nth presentation of the unknown item being learned, and the K sub-ns are the previously learned (Known) items. Once the new (Unknown) item has been presented nine times, the sequence is repeated, but with a new item as the Unknown and the just learned item entering the pool of Known items. By carefully examining this sequence, the reader will see that new items are introduced slowly and are recalled (using retrieval practice) many times, separated by previously learned items (interleaving), according to a schedule where those attempts are further and further apart in time (spaced practice).

Increasing the time *between* practice sessions—called *expanding retrieval review*—is the most efficient approach to building long-term memory (Cull et al., 1996). The simplest approach to implementing this strategy is to schedule review sessions using a geometric series. Information or a skill learned in the morning should be retrieved or practiced in the afternoon. The next retrieval or practice session should occur the very next day, then another two days after that, and another four days after that, and another eight days after that, and so on. The graph below presents the changes in memory strength through initial learning, forgetting, and review sessions. Ultimately, knowledge is permanently stored in memory.



Because individual memories and skills decay at different rates, however, the optimal schedule for review varies for each piece of information. There are several paper-based flashcard systems that implement expanding retrieval review including the Leitner cardbox (Leitner, 1974) and SAFMEDS (Quigley et al., 2018). Software-based systems such as Supermemo (Wozniak, 2018) and Cerego (Van Schaack et al., 2000) create an optimal schedule of retrieval practice for each student on an item-by-item basis.

3. INTERLEAVING

Switching between related problem types while studying and varying the conditions of practice during training improves transfer of knowledge and skills.

Application examples: An instructor designs an in-class activity where his students alternate between studying worked solutions and solving problems. A trainer enhances skill retention and transfer by requiring her trainees to switch between different tasks while she varies the conditions under which they are practicing.

Interleaving is an approach to the design of instruction where different, but related, problems are mixed in a single learning session. One benefit of this approach is that students cannot simply apply the same approach to solving each problem, but instead must first determine which of several approaches is appropriate based on characteristics of the problem itself (Brown et al., 2014). A second benefit of interleaving relates to the spacing of practice. When problems of a different type from previous practice sets are reintroduced into the current practice activity, students must retrieve information from long-term memory to solve the older problem type. Thus, interleaving can be used as the means to create the spacing required for spaced practice. Accordingly, the combined benefits of retrieval practice and spaced practice can be accomplished through the interleaving of different problem types within practice sets, review sessions, and comprehensive examinations (Hughes & Lee, 2019).

Despite the instructional benefits and relative ease of organizing instructional activities using interleaving, blocked practice—where specific problem types are clustered and practiced together before moving on to the next type—is the standard approach used in most mathematics textbooks. In a review of 13,000-plus practice problems drawn from six representative mathematics textbooks, Rohrer et al. (2020) found that less than 10 percent of the problems were interleaved. Accordingly, instructors will most likely need to create their own problem sets if they want their students to realize the benefits of interleaving.

Recommendations for Instructors

1. Interleaving improves test scores only when tests are cumulative (i.e., they include a variety of problems from several units). If a test consists of only one problem type, then blocked practice of that type will produce the best scores. A test that is not cumulative is not ideal, however, if the ultimate goal is for your students to be able to recognize and solve a variety of problems types.

2. After initial blocked practice with a new problem type, interleave worked examples with problems students must solve on their own. As students develop proficiency, reduce the percentage of worked examples in problem sets.

3. Once students can solve a particular problem type on their own, interleave problems of various types from current and previous lessons in both guided and independent practice. A good rule of thumb is that two-thirds of the problems should come from the current lesson and one-third should come from previous lessons.

4. For subjects where content is organized by theme—for example, vocabulary lists in foreign language courses—question sets should include vocabulary from a variety of lists rather than just one.

5. Blocked problems sets are relatively easy since students can apply the same approach to every problem. Interleaved problems sets, on the other hand, are more challenging since the student must select the correct approach as well as solve the problem using it. Accordingly, fewer problems should be included in interleaved practice sets and high-quality feedback is essential.

Recommendations for Students

1. When practicing anything, whether it's a sport like basketball or an academic subject like mathematics, you should mix up the types of skills you are practicing or problems you are solving—not only will you get good at solving each type of problem, you'll also improve your ability to recognize each problem type so you can use the correct method.

2. Be careful: Interleaving is *not* simply jumping from one subject to another while studying. Interleaving works *within* subject areas when practice problems are arranged so that any two problems in a row cannot be solved using the same strategy.

3. When you're studying using flashcards, don't study the cards in one order; mix them up. Keep cards you know in the deck and shuffle it after each round. Better yet, when you miss a card, move it lower in the deck so you see it again soon. Keep doing this until you know them all.

4. If you are studying a foreign language, practice listening to different native speakers say the words and phrases you are learning. Barcroft and Sommers (2005) found that students who listened to foreign vocabulary words from different speakers scored 41% higher on a test than students who only listened to one speaker.

5. When studying for a test that covers a number of different topics, create a study plan where you quiz yourself on different problem types or material in random order. Don't simply study the material in the order that it was presented by your instructor in class.

4. DUAL CODING

Because people process information through two separate channels (verbal and visual), combining words with pictures leads to better learning than from words alone.

Application examples: Images on a screen are described by an instructor with spoken words rather than written words. The instructor also carefully avoids speaking at the same time as her students are reading text on the screen.

According to Paivio (1986), people process information primarily through verbal associations (words) and visual imagery (images). His dual coding theory states that verbal and visual information is perceived and processed in parallel through two separate channels. People are limited, however, by the amount of information that each channel can process at a given time. Optimal instruction maximizes the information processing resources of each channel without overloading either one of them.

Even though words projected onto a screen are perceived with the eyes, they are processed as auditory information similar to spoken words. Therefore, students cannot read text on the screen *and* comprehend what their instructors are saying at the same time; they can only do one or the other without overloading the auditory processing channel. Similarly, when words are projected onto a screen at the same time that images are (e.g., photographs and diagrams), both compete for the limited resources of the visual processing channel. Research on multimedia learning consistently demonstrates that providing spoken descriptions of images being displayed makes the presented information easier to process. It is important, however, for instructors to give students enough time to integrate the two representations (LeFevre & Dixon, 1986; Mayer & Gallini, 1990).

Note: Dual coding is frequently referred to as "multimedia learning" because the information is presented using multiple media types (words and images).

Recommendations for Instructors

1. Describe images presented on-screen with spoken words rather than written words.

2. Avoid speaking at the same time that students are reading text on the screen. Pause for the amount of time it takes you to quickly read through it twice. If the text is too small for students to read, read the text out loud to them or make it larger and divide it between two slides.

3. Make it easy for students to make connections between what you are saying and the image on-screen. You can do this by pointing to specific areas of the image and explicitly describing them. You can say, for example “As you see in the upper right-hand corner…”, “Notice that the green arrow indicates the direction of…”, and “The cells highlighted in red represent…”.

4. Exclude non-essential sound effects, music, animations, and decorative images (including clip art). All of these make use of cognitive resources students need to process information. Unless a resource is *essential* to understanding a key concept, remove it.

5. Do *not* modify your instruction based on learning styles. Although most educators and students believe that every person has a style most effective for learning (auditory, visual, or kinesthetic), it’s not true (Pashler et al., 2008). What *is* true is that specific types of information or skills are best taught using a particular modality, e.g., music appreciation–auditory; art history–visual; and throwing a ball–kinesthetic. Most subject matter requires at least two presentation modalities which highlights the importance of effective multimedia instruction.

Recommendations for Students

1. When studying your class materials, find diagrams in your notes or textbook and describe them in your own words. Next, compare your explanations with those provided by your instructor or the textbook.

2. Draw pictures of the things you are learning about. They could be flow charts of processes, timelines of events, tables to compare features of two or more things, or diagrams where you label the parts.

3. Place labels for elements in a diagram close to the associated element rather than in a legend on the side or the bottom of the diagram. It’s easier to study a labeled diagram when you don’t have to search for the name of a part you are looking at.

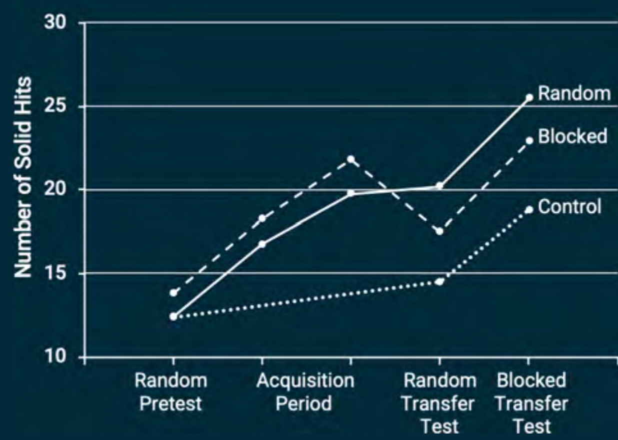
4. Avoid listening to music while you are studying. The lyrics will compete with the words you are reading and make it difficult to comprehend them. The only exception to this rule is when there is distracting background noise—in this case, *instrumental* music (i.e., music without lyrics) can help to block out the noise (Dobbs et al., 2011).

5. Although many instructors and students believe every person has a style most effective for learning (auditory, visual, or kinesthetic), it’s not true. Don’t fall into the trap of believing you can’t learn something because the way it is being taught doesn’t match what you think is your best learning style. Instead, use the strategies described in this document—they’ve been proven to be very effective for students just like you.

EVIDENCE FOR INTERLEAVING

Hall et al. (1994) investigated the benefits of interleaved practice on skilled athletic performance. The researchers scheduled biweekly extra batting practice where collegiate baseball players practiced hitting 15 fastballs, 15 curveballs, and 15 change-up pitches. Players were randomly assigned to two groups with the only difference being the order in which the pitches were thrown to them. In the Random condition, the pitches were thrown in random order. In the Blocked condition, all of the fastballs were thrown first, followed by the curve balls, and finally, the change-up pitches. After six weeks of practice (12 sessions), the players were tested under two different conditions. In the random transfer test, 45 pitches were thrown to the batters in random order. In the blocked transfer test, 45 pitches were thrown to the batters in blocked order. Although there was no statistically significant difference between the two groups at the beginning of the experiment, there were large differences in performance at the end of the training period.

When comparing the performance of the pretest to the random posttest—the condition that most closely matches what happens in a real game—the Random group improved 56.7% from baseline whereas the Blocked group improved only 24.8%. A Control group that received no extra batting practice improved by 6.2%. Players who were thrown pitches in random order during practice improved their batting performance on the test by more than *twice* as much as those who practiced with a blocked order of pitches. The improvement of the Control group between the pretest and posttest can be explained by the fact that all players in the experiment participated in regular batting practice during the experiment.



Random practice is particularly appropriate when decision-making regarding the type of skill to apply is required (Birnbaum et al., 2012). During a game, a batter must (very quickly) identify the type of pitch thrown to determine when and how to swing the bat. This is an example of "discrimination learning." Random practice not only provides players with opportunities to practice their swing, but also to identify the type of pitch thrown—an essential skill to develop if they are to have any hope of getting a base hit during a game.

PRINCIPLES OF MULTIMEDIA DESIGN

Principle	Description	Recommendation
Coherence Principle	People learn better when extraneous words, pictures, and sounds are excluded from presentations.	Remove nonessential images or words or images. Weed out the clutter.
Signaling Principle	People learn better when cues that highlight the organization of the essential material are added.	Chunk information into categories. Use ordered lists. Highlight essential parts by calling attention to them.
Redundancy Principle	People learn better from graphics and narration than from graphics, narration, and on-screen text.	Do not initially speak words that are different than those that are presented on the screen at the same time.
Spatial Contiguity Principle	People learn better when pictures with corresponding words are presented close each other.	Place diagram labels next to what they are labeling rather than in a separate, numbered table.
Temporal Contiguity Principle	People learn better when animations and narration are presented at the same time rather than successively.	Synchronize narration to the images that appear on the screen.
Segmenting Principle	People learn better when instruction is presented in user-paced, short segments rather than one long unit.	In computer-based training, provide "next" and "replay" buttons. Break down instruction into" bite-sized" segments.
Pre-Training Principle	People learn better from a multimedia lesson when they know the names and characteristics of the main concepts.	Ask students to study essential vocabulary, definitions, or concepts in advance of classroom instruction.
Modality Principle	People learn better from images and spoken narration than from images and on-screen text.	Don't overload the visual channel with images and printed words, or the auditory channel with printed and spoken words.
Multimedia Principle	People learn better from words and pictures than from words alone.	Reduce the number of words on screen. Narrate the images you present.
Personalization Principle	People learn better when words are spoken in a conversational tone rather than a formal one.	Speak to the learner not at them. Use personal pronounces (I, you) to make learners feel involved.
Voice Principle	People learn better when multimedia narration is spoken in a friendly human voice rather than a machine voice.	In computer-based training, use recorded human voices instead of computer-generated ones.
Image Principle	People do not necessarily learn better from a multimedia lesson when the speaker's image is added to the screen.	Avoid using a static or video image of the instructor in computer-based training (except at the beginning).

Mayer, R. E. (2006). *Multimedia learning*. Cambridge University Press.

5. CONCRETE EXAMPLES

Using specific, real-world examples to explain abstract ideas makes those ideas easier to understand, remember, and use.

Application example: An instructor introduces a new concept to her students in abstract form first (using a simple diagram) and then provides a range of concrete examples (using photographs) highlighting the relevant features across all forms.

Declarative concepts are key terms within a subject area usually defined using one or two sentences. For example, physics students learn about buoyancy and refraction while psychology students learn about memory and motivation. In athletics, soccer players learn about the offside penalty and free kicks, and in the culinary arts, aspiring chefs learn about roasting meat and sautéing vegetables.

Instructors spend a great deal of time teaching their students about declarative concepts. Textbooks contain dozens, if not hundreds, of concepts throughout. Time devoted to teaching concepts is well-spent since they form the foundation for everything learned within a subject area.

A common approach in textbooks and classroom instruction is to introduce a declarative concept with its definition followed by several concrete (illustrative) examples. The goal is for students to be able to apply their knowledge of the concept to identifying new examples or to create examples of their own. This is one of the hallmarks of conceptual learning.

Recommendations for Instructors

1. It's important to immediately connect and integrate abstract and concrete representations of a concept. It's easiest for students to gain an initial understanding of a concept by presenting a concrete example. The risk, however, is that their understanding of the concept is limited to superficial characteristics of the example provided. (If you teach the concept of "dog" using a German Shepherd, for example, some students may think that *all* dogs look like German Shepherds.)* Accordingly, multiple concrete examples should be provided that vary in their qualities while remaining true to the concept.

2. A common mistake is attempting to teach a concept using only accurate examples of it; it's critical that you interleave non-examples as well. ("This [poodle image] is a dog." "This [wolf image] is *not* a dog." "This [fox image] is *not* a dog.") Examples and non-examples should be presented side-by-side to enable your students to easily identify the essential features.

3. After the initial presentation of an abstract concept with several concrete examples, students should be encouraged to create their own abstract representation (e.g., simplified drawing) to improve their ability to recognize the concept in different contexts. Their drawings should include all of the essential features.

4. Ask a student to explain how two different examples represent an abstract concept by identifying the essential features. Ask other students to use the first student's description of the essential features to generate new examples to see if it's an accurate description.

* Notice how this concrete example was helpful?

Recommendations for Students

1. When an abstract concept is presented by your teacher or appears in a book, try to think of several concrete examples of it. If given one or more concrete examples, see if you can determine the abstract concept they all represent (e.g., "Bat, dog, and whale: What do they all have in common? They're mammals."). Check with your instructor to make sure your ideas are correct.

2. Use concrete examples that you know are correct to help you define a set of rules to identify more examples. Test examples you know are not correct to see if your rules are clear-cut and accurate. Share your rules with your teacher to see if you understand the abstract concept correctly.

3. When thinking of concrete examples of an abstract concept, try to think of some examples that are not correct, but are very close. This will help you to define the boundaries of the concept. Use your examples to quiz your study partners.

4. When thinking of concrete examples of an abstract concept, make the examples as different from each other as possible while still including all of the essential features. Don't simply name three basketball players if you're thinking of examples of "athlete," include archers, rock climbers, and athletes who use wheelchairs.

5. If you can't think of many concrete examples or you need help thinking of ones that are different from the ones you already have, search for images on the internet related to the concept. Be careful, though, not all of them will be correct examples. Test them using the definition provided by your teacher.

6. ELABORATION

Using specific, real-world examples to explain abstract ideas makes those ideas easier to understand, remember, and use.

Application examples: An instructor guides his students to ask "how" and "why" questions about the causes of the American Civil War, to connect what they're currently learning about this war to what they had previously learned about the Revolutionary War, and to create a table showing similarities and differences between the two.

Learning through elaboration is the process of developing an understanding of information by connecting it to what is already known, expanding upon it, and organizing it in meaningful ways. Accordingly, learning not only depends on how information is presented by the instructor, but more importantly, on how students process the information to make sense of it.

Knowledge isn't stored in the brain as isolated pieces of information, it's stored as an interconnected *network* of information. When a student is presented with new information, their knowledge network is activated as they form connections with what is already stored in long-term memory. The more connections made, the more likely it is that they can retrieve the information in the future since there are more ways for them to access it.

Elaboration and self-explanation are two related learning strategies students can use to make deep and wide connections. Students can elaborate on the concepts they are learning by asking themselves "*how*" and "*why*" questions and then actively constructing explanations. Self-explanation is a content-independent process where a student monitors their own learning process and asks themselves questions such as, "*How can I put this idea into my own words?*". Students should be encouraged to ask themselves the questions frequently posed to them by their best instructors when they are studying on their own.

A useful way to think about elaboration is by the *depth* with which information is processed (Craik and Lockhart, 1972). Information that is processed at a *surface* level is often forgotten immediately. Examples include a student who reads a paragraph or looks at a graph without much thought. They may recognize the information if it is presented to them again in the future, but they couldn't recall it on their own. Information processed more deeply, but still at a moderately *shallow* level, is more memorable and useful, but because there is relatively little understanding, it's likely to be of limited value in novel situations in the future. Information processed *deeply*, however, is likely to remain memorable for a long time, and when needed, can be used to solve related, but new problems.

Recommendations for Instructors

1. Ask students to make connections between new material and what they already know. When reviewing previously learned material (using retrieval practice), ask students to make connections between it and material they are currently in the process of learning.

2. Design assignments for your students that require them to explain *how* or *why* something happened. A more advanced version is to ask, *"What if…?"* questions. Since determining relevance requires elaboration, ask your students how they could apply their new knowledge or skills in their personal lives or professional careers.

3. Ask students to explain an idea in their own words rather than simply providing a memorized response. Phrase your questions to them like "Explain this in a way your friend would understand. Assume your friend is intelligent but doesn't know anything about the subject." Add that their friend would probably appreciate examples, analogies, or diagrams.

4. Create a standard series of questions for elaboration and self-explanation and use them consistently with your students. After a while, the questions will become second nature and they will use them when they are studying on their own. *"Why is this true?," "What caused X?," "What if…?," "What are the similarities between X and Y?," "How is X different from Y?," "Why is X important?," "Where have you seen an example of X in your everyday life?," "What is another example of X?,"* and *"Why is this true for this X but not for that X?"*.

Recommendations for Students

1. The most powerful application of elaboration is making connections between the things you are currently learning and the things you already know. The more connections the better. Create analogies to explain how two concepts are similar. For example, "Electricity flowing through a circuit is like water flowing through a pipe because…"

2. Ask yourself questions about *how* or *why* things work the way they do and then answer your own questions. Create explanations that you think a friend would understand by using examples, analogies, or diagrams.

3. Organize the information you are learning about using visual representations such as tables, process diagrams, or troubleshooting flowcharts. Summarize important ideas in your own words—they will be easier for you to recall in the future than memorized definitions and descriptions.

4. Help other students who are struggling to understand the course material. Peer tutoring is as beneficial to you as it is to the person you are helping. Tutoring requires you to organize your ideas and explain them clearly. Organizing your ideas will help you to remember them longer and apply them outside the classroom.

5. Think about how what you are learning could be relevant in your personal life or professional career. Making these connections is a form of elaboration that will make the material more memorable and you will be more motivated to study it once you realize how useful it can be to you.

EVIDENCE FOR ELABORATION

Fiorella and Mayer (2014) hypothesized that learning through teaching could significantly improve a student's understanding of course content. In the process of putting the key concepts into their own words, thinking of examples and analogies, and preparing their responses to anticipated questions, they would be engaging in elaboration and self-explanation—methods known to produce deep information processing. In order to test their hypothesis, they conducted an experiment with 104 undergraduates.

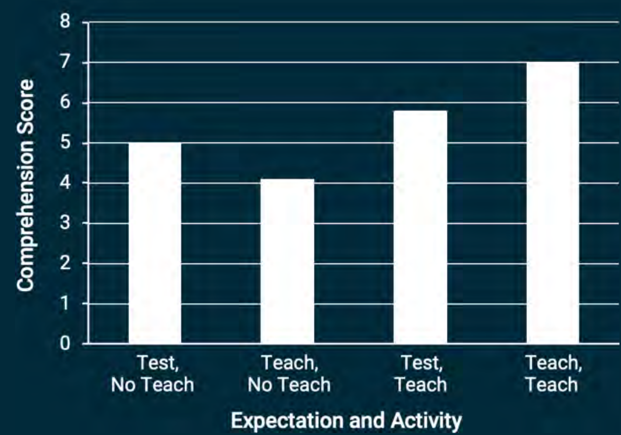
Expect Test–No Teach group members were told they would have 15 minutes to study a lesson on the Doppler Effect and then answer questions about it.

Expect Teach–No Teach group members were told they would have 15 minutes to study the lesson and an additional five minutes to create a video of them teaching the material. They studied for 15 minutes but didn't actually create an instructional video.

Expect Test–Teach group members were told they would have 10 minutes to study the lesson and then would answer questions on the material. They studied for 10 minutes and were then given 5 minutes to create a video of them teaching the material.

Expect Teach–Teach group members were told they would have 15 minutes to study the lesson and an additional 5 minutes to create a video of them teaching the material. They studied for 10 minutes and were then given 5 minutes to create a video of them teaching the material.

One week after completing the first part of the experiment, students returned for the second part where they took a comprehension test.



Students in the two groups that taught the material through the creation of instructional videos outperformed students in the other groups who simply studied the material. Most important, the highest comprehension scores were achieved by the students who prepared to teach the material *and* created a video. This contrasts with the students with the lowest scores: those who thought they were going to teach but didn't. This answers the key question posed by the researchers: For individuals to realize the benefits of elaboration through teaching, is it enough for them to simply *prepare* a lesson or do they actually need to *deliver* it? Delivering a lesson, beyond simply preparing it, increases comprehension by over 70%.

The effectiveness of teaching as an instructional activity is the result of elaboration and retrieval practice. First, students must develop an organized, coherent structure for the information in their own minds in order to create relevant and meaningful explanations for their peers. When students teach the lesson, they engage in retrieval practice and must generate new explanations in response to the questions of their peers. These activities require students to process the information deeply—a primary goal of instruction.

ELABORATION STRATEGIES

Cold Call Technique

If there is one golden rule in education and training, it is this: People learn better when they have more opportunities to perform with feedback.

The most effective strategy to increase student engagement while promoting frequent retrieval practice for *all* students is “cold calling.” Rather than asking a question and then calling on a student who raised their hand or calling on a student and then asking them a question, you should instead ask a question, pause for three seconds, and then call on a student (usually at random) to respond. Putting a student’s name at the *end* of a question rather than the *beginning* of it changes everything. When you call on a student and ask them a question, other students will passively watch and listen. When you ask a question, pause, and then call on a student, *every* student will prepare a response to *every* question.

Cold calling is only effective when it is reasonable to expect that students know the answer or can perform a desired action. Conversely, if students are asked questions they cannot reasonably answer—especially if it is viewed as an attempt to punish them (sometimes called “shotgunning”)—they will likely become resentful and disengage.

If a student cannot provide a correct response, an effective approach Is to ask the other students to offer a hint. This will provide all students the opportunity to retrieve the information and elaborate on it.

All correction procedures should include an opportunity for the student to provide the correct response, and ideally, a second opportunity to confirm their understanding later in the lesson (Watkins & Slocum, 2004). Checks for understanding should be performed through quick, low-stakes quizzes, *never* by asking, “*Does this make sense?”* or “*Any questions?*”.

Surface Processing

who what when where why how define label show match list explain compare contrast relate translate demonstrate rephrase outline interpret find

Can you recall…?”
How would you describe…?
What is the main idea of…?
What is another example of…?
How would you compare…?
How would you interpret…?
How would you summarize…?

Shallow Processing

develop select model organize build analyze choose interview plan simplify categorize solve inspect test examine discover assumption dissect conclusion

Can you develop a model that…?
How would you organize…?
What would happen if…?
What motive would there be…?
What is the relationship…?
What evidence supports…?
How could you simplify…?

Deep Processing

Interpret justify judge evaluate assess influence recommend critique evaluate select decide prioritize design invent solve improve maximize predict rate

Would it be better if…?
What choice would you make…?
Which is better and why?
How could you improve…?
How would you optimize…?
How would you predict…?
What would be a new way to…?

DESIRABLE DIFFICULTIES

A study sponsored by the U.S. Army Research Institute and conducted by Schmidt and Bjork (1992), *New Conceptualizations of Practice: Common Principles in Three Paradigms Suggest New Concepts for Training,* should be required reading for anyone involved in the design and delivery of education and training.

The authors describe one of the most important but counterintuitive findings from research in education and training: Instructional strategies that maximize speed of acquisition and immediate performance often lead to the poorest long-term retention and transfer. The introduction of “desirable difficulties” during the learning process—even though they slow the rate of acquisition and reduce initial performance—produces more durable knowledge and skills that can be used in varied contexts in the future. Very simply, when it comes to learning, easier isn’t better.

Instructional Manipulation	Conventional Training	Desirable Difficulties
Learning or practice conditions	Constant, predictable	Varied, unpredictable
Schedule of problems or tasks	Blocked (AAABBBCCC)	Interleaved (ABCABCABC)
Schedule of study or practice	Massed (cramming)	Spaced out over time
Depth of processing	Shallow	Deep
Feedback	Constant	Intermittent
Purpose of testing	Assessment	Learning (through retrieval practice)
Immediate Training Results	Faster acquisition; higher performance	Slower acquisition; lower performance
Long-Term Training Results	Rapid forgetting; lower transfer	Long-term retention; higher transfer

The objective of “desirable difficulties” is not simply to make learning *hard*, but to deliver instruction with *carefully designed difficulties* that promotes the kind of information processing that results in long-term retention and transfer.

The primary reason why almost all training follows the conventional approach is that instructors and students mistake *performance* (current indications of how well a student is doing) for *learning* (long-term retention and transfer of knowledge and skills). In conventional training, instructors and students are rewarded by the instant gratification that comes from rapid acquisition and immediate, successful performance. Unfortunately, this reward comes at the expense of achieving the true, long-term learning objectives.

Fundamentally, people learn best when they are provided many opportunities to perform (and makes errors) with feedback. Instructional methods that minimize the likelihood of student errors deny them the opportunity to learn what they know and don’t know and what they can do and cannot do. The errors the students would have made during training are deferred to the post-training environment where performance matters the most.

CONCLUSION

To understand the value of the six key psychological principles and the instructional strategies associated with them, it is worthwhile to compare them to improvements considered significant in the disciplines of medicine and engineering.

The *Physician's Health Study* was an eight-year experiment designed to determine the effects of daily aspirin use on reducing the incidence of heart attacks. The study was terminated after five years, however, due to ethical concerns (Data Monitoring Board of the Physicians Study, 1991). Because only 0.90% of the subjects in the aspirin group suffered heart attacks compared to 1.55% in the placebo group, it was deemed unethical to deny the placebo group the aspirin regimen. The difference of 0.65% was considered clinically and practically significant. It is estimated that over 100,000 lives are saved every year, worldwide, as a result of daily aspirin use by those for whom it is prescribed (Antiplatelet Trialists' Collaboration, 1994).

In the mid-1970s, research by Whitcomb (1976) at NASA's Langley Research Center revealed that the addition of a winglet—a small vertical fin at the tip of an aircraft wing—reduces in-flight drag by up to 6.5%. Following two decades of additional research and development, aircraft manufacturers began retrofitting their aircraft with winglets in the early 2000s. Recent reports by airline operators indicate a real-world reduction in fuel consumption of 3% (Freitag & Schulze, 2021). By 2020, nearly all aircraft operated by commercial airlines have designs that incorporate winglets producing an annual savings of over $1 billion for domestic U.S. flights alone.

The instructional strategies described in this handbook produce much larger effects than aspirin (0.6%) and winglets (3%). *The average performance improvement observed in the cited studies is 100%.* That is, instructors using the recommended instructional strategies saw outcome scores for their students that were often *twice* that of the comparison group. Several individual studies were much larger. It is important to note that the comparison groups in the studies were not simply control groups that "did nothing" or received a placebo; they used conventional approaches favored by most instructors and students.

The instructional strategies are based on experimental evidence produced over several decades by thousands of research scientists. They provide instructors and students the fundamental tools needed to maximize the effectiveness and efficiency of education and training programs where the objectives are long-term retention and transfer of knowledge and skills. What is also required, however, is for instructors and students to acknowledge their commitment to excellence and to embrace these new approaches, even when they appear to contradict conventional wisdom and personal intuition.

Courage is the power to let go of the familiar.

– Raymond Lindquist

REFERENCES

Agarwal, P. K., Karpicke, J. D., Kang, S. H. K., Roediger, H. L., & McDermott, K. B. (2008). Examining the testing effect with open- and closed-book tests. *Applied Cognitive Psychology*, *22*(7), 861–876.

Antiplatelet Trialists' Collaboration (1994). Collaborative overview of randomised trials of antiplatelet therapy: Prevention of death, myocardial infarction, and stroke by prolonged antiplatelet therapy in various categories of patients. *British Medical Journal*, *308*(6921), 81–106.

Ariel, R., & Karpicke, J. D. (2018). Improving self-regulated learning with a retrieval practice intervention. *Journal of Experimental Psychology: Applied*, *24*, 43–56.

Barcroft, J., & Sommers, M. S. (2005). Effects of acoustic variability on second language vocabulary learning. *Studies in Second Language Acquisition*, 27(3), 387–414.

Binder, C. (1996). Behavioral fluency: Evolution of a new paradigm. *The Behavior Analyst*, *19*, 163–197.

Birnbaum, M. S., Bjork, E., Bjork, R. A., & Kornell, N. (2012). Why interleaving enhances inductive learning: The roles of discrimination and retrieval. *Memory & Cognition*, *41*(3), 392–402.

Broeren, M., Heijltjes, A., Verkoeijen, P., Smeets, G., & Arends, L. (2021). Supporting the self-regulated use of retrieval practice: A higher education classroom experiment. *Contemporary Educational Psychology*, *64*, 101939.

Brophy, J. E., & Good, T. L. (1986). Teacher behavior and student achievement. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed, pp. 328–375). Macmillan.

Brown, P. C., Roediger III, H. L., & McDaniel, M. A. (2014). *Make it stick: The science of successful learning*. Random House.

Carpenter, S. K, Cepeda, N. J., Rohrer, D., Kang, S. H. K., & Pashler, H. (2012). Using spacing to enhance diverse forms of learning: Review of recent research and implications for instruction. *Educational Psychology Review*, *24*, 369–378.

Carpenter, S. K., & DeLosh, E. L. (2006). Impoverished cue support enhances subsequent retention: Support for the elaborative retrieval explanation of the testing effect. *Memory & Cognition*, 34(2), 268–276.

Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*(6), 671–684.

Cull, W. L., Shaughnessy, J. J., & Zechmeister, E. B. (1996). Expanding our understanding of the expanding pattern of retrieval mnemonic: Toward confidence in applicability. *Journal of Experimental Psychology: Applied*, *2*, 365–378.

Data Monitoring Board of the Physicians Study, Cairns, J., Cohen, L., Colton, T., DeMets, D. L., Deykin, D., Friedman, L., Greenwald, P., Hutchison, G. B., & Rosner, B. (1991). Issues in the early termination of the aspirin component of the Physicians' Health Study. *Annals of Epidemiology*, *1*(5), 395–405.

Dobbs, S., Furnham, A., & McClelland, A. (2011). The effect of background music and noise on the cognitive test performance of introverts and extraverts. *Applied Cognitive Psychology*, *25*(2), 307–313.

Driskell, J. E., Willis, R., & Cooper, C. (1992). Effect of overlearning on retention. *Journal of Applied Psychology*, *77*, 615–622.

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving students' learning with effective learning techniques. *Psychological Science in the Public Interest*, *14*(1), 4–58.

Ebbinghaus, H. (1885). *Memory: A contribution to experimental psychology* (H. A. Ruger & C. E. Bussenues, Trans.). Teachers College, Columbia University.

Fiorella, L., & Mayer, R. E. (2015). *Learning as a generative activity: Eight learning strategies that promote understanding.* Cambridge Univ. Press.

Freitag, W., & Schulze, E. T. (2021). Blended winglets improve performance. *Aero Quarterly*, *35*(3), 8–12.

Glover, J. A. (1989). The "testing" phenomenon: Not gone but nearly forgotten. *Journal of Educational Psychology*, *81*(3), 392–399.

Hall, K. G., Domingues, D. A., & Cavazos, R. (1994). Contextual effects with skilled baseball players. *Perceptual and Motor Skills*, *78*, 835–841.

Hughes, C. A., & Lee, J. Y. (2019). Effective approaches for scheduling and formatting practice. Distributed, cumulative, and interleaved practice. *Teaching Exceptional Children*, *51*(6), 411–423.

Karpicke, J. D. (2017). Retrieval-based learning: A decade of progress. In J. T. Wixted (Ed.), *Cognitive psychology of memory, Vol. 2 of Learning and memory: A comprehensive reference* (pp. 487–514). Academic Press.

Karpicke, J. D., & Bauernschmidt, A. (2011). Spaced retrieval: Absolute spacing enhances learning regardless of relative spacing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(5), 1250–1257.

Karpicke, J. D., & Roediger, H. L. (2008). The critical importance of retrieval for learning. *Science*, *319*(5865), 966–968.

Kornell, N., & Bjork, R. A. (2008a). Optimising self-regulated study: The benefits—and costs—of dropping flashcards. *Memory*, *16*(2), 125–136.

LeFevre, J. A., & Dixon, P. (1986). Do written instructions need examples? *Cognition and Instruction*, 3, 1–30.

Leitner, S. (1974). *So lernt man lernen*. Herder Verlag.

Mayer, R. E., & Gallini, J. K. (1990). When is an illustration worth ten thousand words? *Journal of Educational Psychology*, *82*, 715–726.

Pashler, H., McDaniel, M., Rohrer, D., & Bjork, R. (2008). Learning styles: Concepts and evidence. *Psychological Science in the Public Interest*, *9*, 105–119.

Paivio, A. (1986). *Mental representations: A dual coding approach*. Oxford University Press.

Quigley, S. P., Peterson, S. M., Frieder, J. E., & Peck, K. M. (2018). A review of SAFMEDS: Evidence for procedures, outcomes and directions for future research. *Perspectives on Behavior Science*, *41*(1), 283–301.

Roediger III, H. L., Putnam, A. L., & Smith, M. A. (2011). Ten benefits of testing and their applications to educational practice. *Psychology of Learning and Motivation*, *55*, 1–36.

Rohrer, D., Dedrick, R. F., Hartwig, M. K., & Cheung, C. N. (2020). A randomized controlled trial of interleaved mathematics practice. *Journal of Educational Psychology*, *112*(1), 40–52.

Schmidt, R. A., & Bjork, R. A. (1992). New conceptualizations of practice: Common principles in three paradigms suggest new concepts for training. *Psychological Science*, 3(4), 207–218.

Tucker, J. A., & Burns, M. K. (2016). Helping students remember what they learn: An intervention for teachers and school psychologists. *Communiqué*, *44*(6), 23.

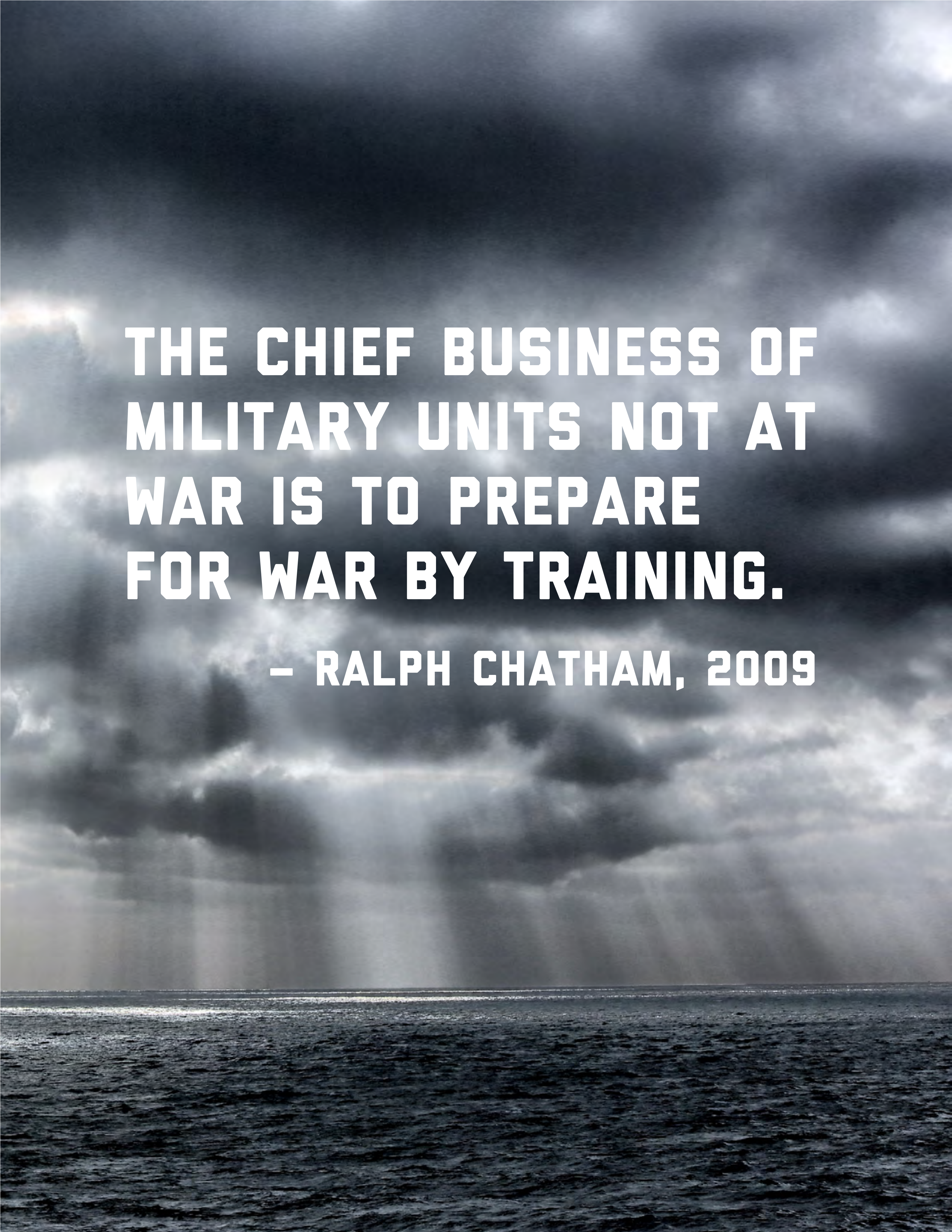
Van Schaack, A. J., Schweighofer, N., & Smith-Lewis, A. (2000). *A new method to maximize the effectiveness and efficiency of learning, memory, and performance.* https://pages.evolve.elsevier.com/Cerego-Method.htm

Watkins, C., & Slocum, T. (2004). The components of Direct Instruction. In N.E. Marchand-Martella, T.A. Slocum, & R.C. Martella (Eds.), *Introduction to Direct Instruction* (pp. 28–65). Allyn & Bacon.

Whitcomb, R. T. (1976). *A design approach and selected wind-tunnel result at high subsonic speed for wing-tip mounted winglets.* NASA TN-D-8260.

Wozniak, P. A. (2018). The true history of spaced repetition. https://www.supermemo.com/en/articles/history

NOTES


THE CHIEF BUSINESS OF MILITARY UNITS NOT AT WAR IS TO PREPARE FOR WAR BY TRAINING.
– RALPH CHATHAM, 2009

NAVAL EDUCATION AND TRAINING COMMAND

FLEET READINESS STARTS HERE