

PRACTICAL APPLICATIONS OF LEARNING SCIENCE

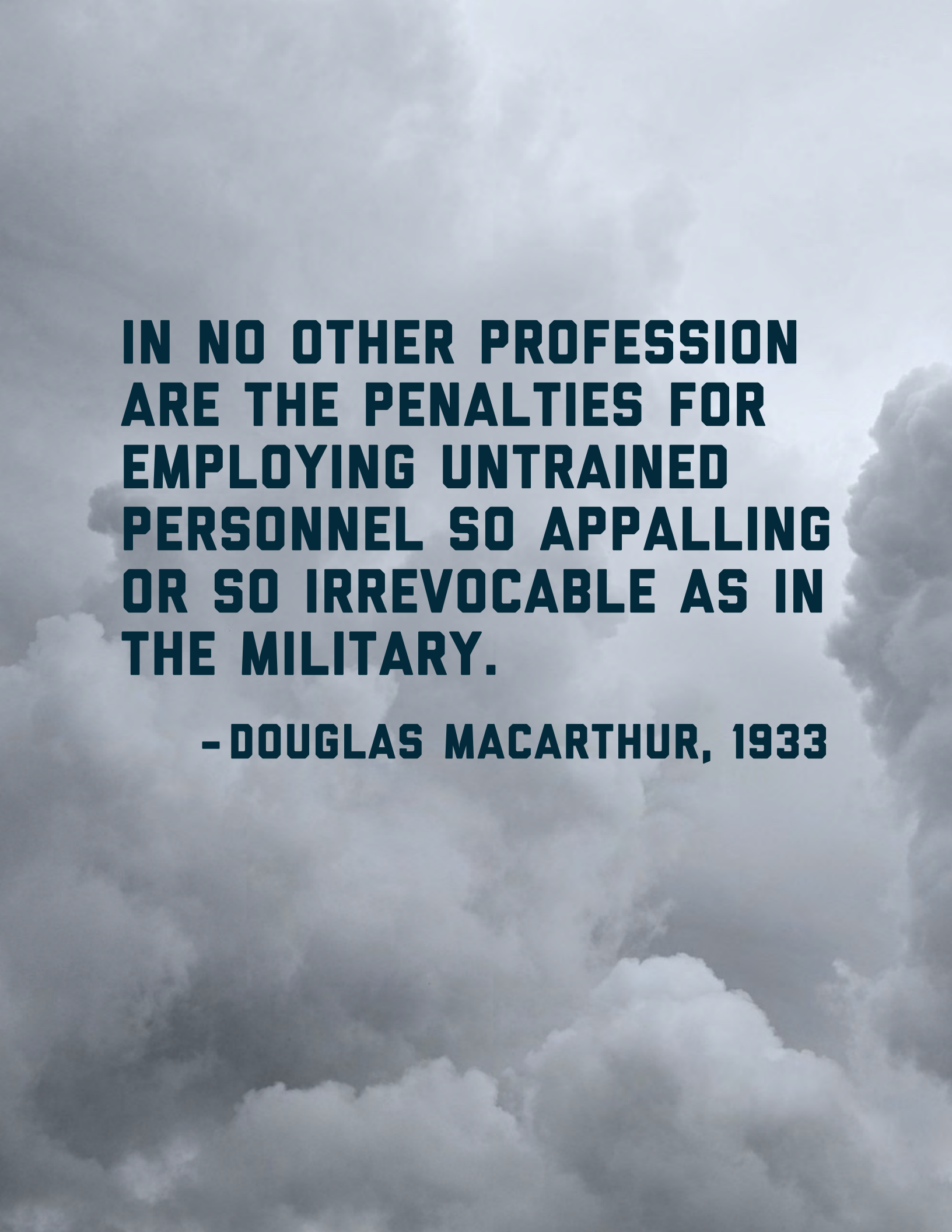


A HANDBOOK FOR NAVAL INSTRUCTORS

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AMERICA'S
NAVYTM



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

- DOUGLAS MACARTHUR, 1933

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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).



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.



EVIDENCE FOR PRACTICE STRATEGIES

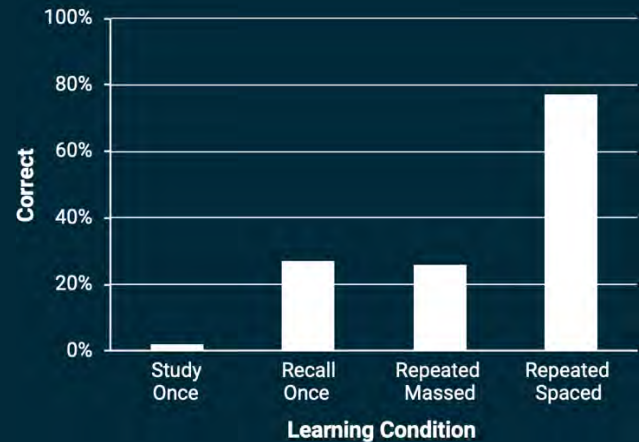
Karpicke and Bauernschmidt (2011) conducted an experiment to determine the differential effects of “studying” foreign vocabulary words by reading them side-by-side (e.g., malkia – queen), and “recalling” them—using retrieval practice—by typing in the English translations of a Swahili words presented 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).

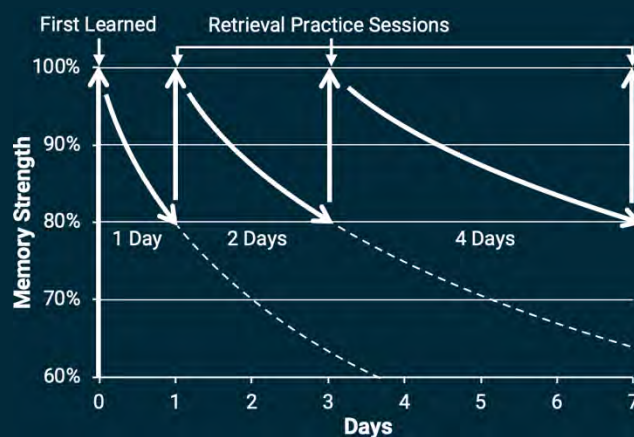
Fortunately, there is an extensive body of scientific literature that describes strategies that promote fluency—"the fluid combination of accuracy plus speed that characterizes competent performance" (Binder, 1996, p. 164). One such approach that combines retrieval practice, spaced practice, and interleaving 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:

$U_i K_1 U_1 K_1 K_2 U_2 K_1 K_2 K_3 U_3 K_1 K_2 K_3 K_4 U_4 \dots$

Where U_{sub-i} is the initial presentation (using retrieval practice) of the unknown item, U_{sub-n} is the n th presentation of the unknown item being learned, and the K_{sub-n} s 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 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 card-box (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.



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).

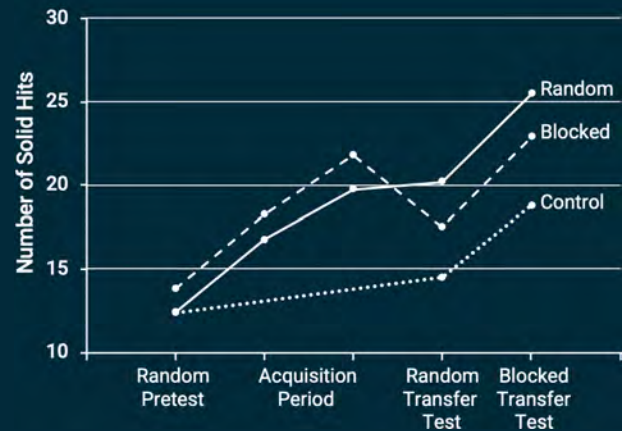
Note: Dual coding is frequently referred to as “multimedia learning” because the information is presented using multiple media types (words and images).



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 pronouns (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.



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.



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.

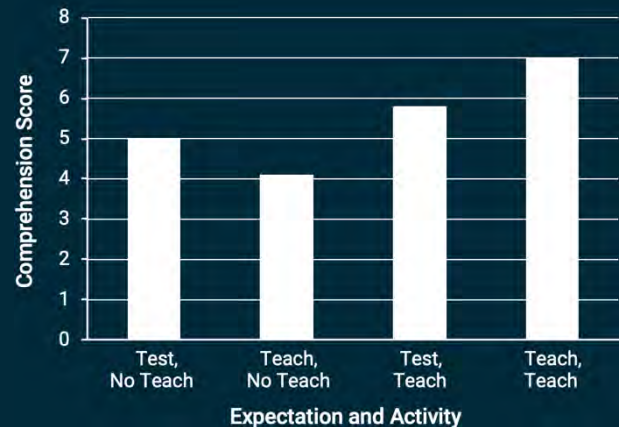
Expect Test–No Teach group members were told they would have 15 minutes to study a lesson on the Doppler Effect and then answer questions about it.

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

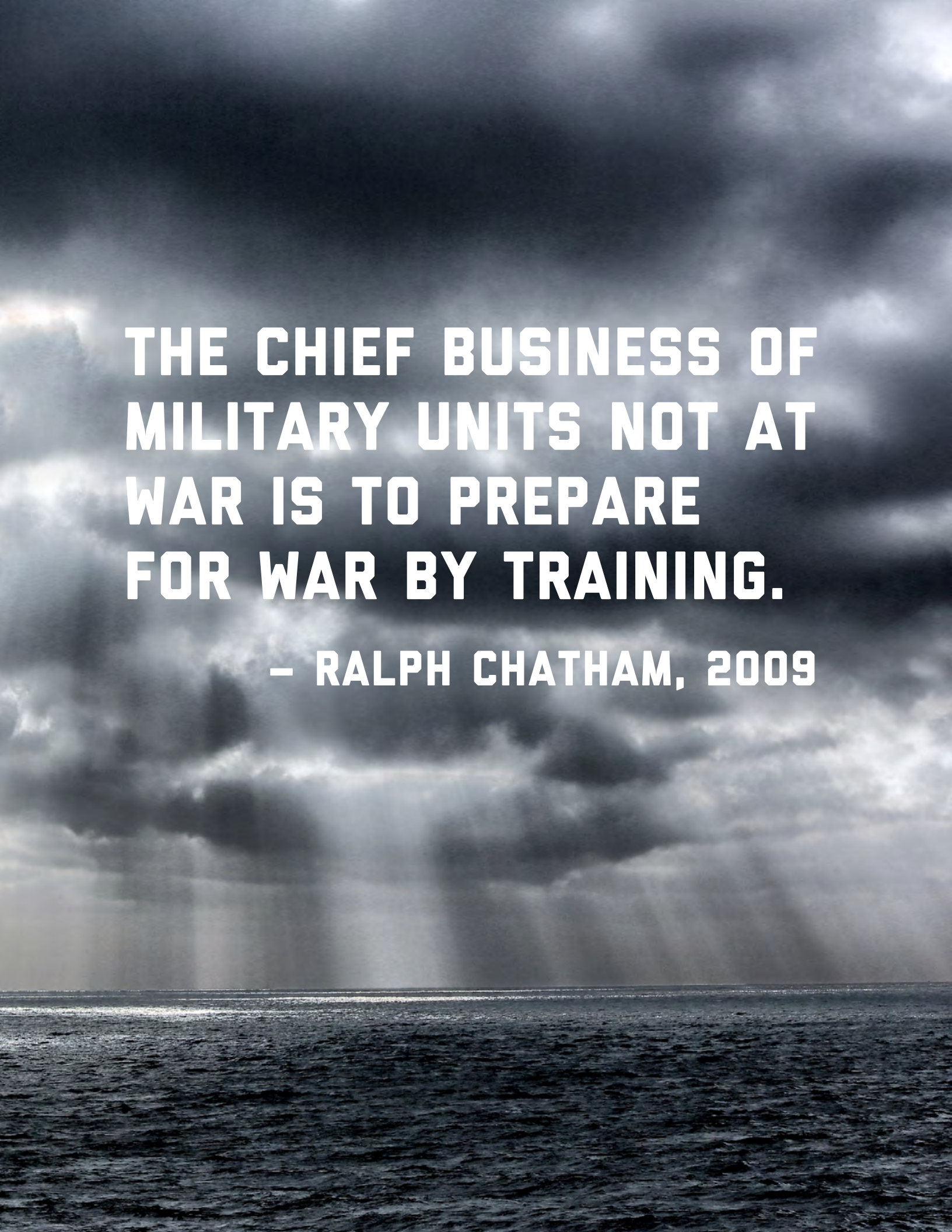
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NOTES

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



**THE CHIEF BUSINESS OF
MILITARY UNITS NOT AT
WAR IS TO PREPARE
FOR WAR BY TRAINING.**

– RALPH CHATHAM, 2009

