

## **CHAPTER OUTLINE**

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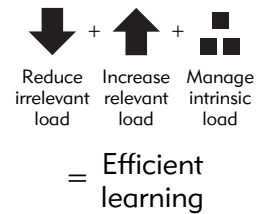
#### **On the CD**

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# 1

## Cognitive Load and Efficiency in Learning



**INFORMATION OVERLOAD AND LARGE FINANCIAL INVESTMENTS** in worker learning and training demand efficient instructional environments. Efficient instructional environments lead to better learning, faster learning, or both because they make the best use of limited human cognitive capacity. This book offers practical proven guidelines to make your instruction efficient.

In this chapter we set the stage by introducing cognitive load theory, which is the scientific basis for efficiency in learning. We will look at three types of cognitive load you must consider in your training, as well as the variations in cognitive load resulting from the interaction among instructional environments, learner prior knowledge, and the complexity of the learning task.

Unlike many books offering training tips and techniques, our guidelines are based on recent valid scientific evidence. We will introduce the type of evidence that we present throughout the book and, since cognitive load theory is fundamentally about efficiency, we will define efficiency and show how it is measured in research studies.

## The Costs of Inefficient Instruction

This is a book about how to create efficient learning environments. The guidelines in this book apply to all types of instructional delivery media, including computers, workbooks, and instructors. Instructional settings that are efficient result in learning that is faster and/or better than settings that are inefficient. Many popular books on learning and training techniques are based on little more than personal opinion. In contrast, our guidelines are based on scientific evidence—evidence accumulated over the past twenty-five years by an international team of instructional scientists. This evidence has important economic implications. As a consequence of high investments made in training programs coupled with rampant information overload, inefficient instructional environments exert a high toll in wasted economic and human resources.

How high is our training investment? From customer service to manufacturing—from sales to supervision—*50 to 60 billion dollars* are spent each year on organizational training programs in the United States alone (Dolezalek, 2004). And this is a low estimate because it does not factor in the hidden costs that make up the most expensive element of any training program—the salary time of participants being trained. While staff are attending a week of training, they are earning their salaries and they are not producing. Even if we disregard lost opportunity costs, just adding the salary costs alone would bring the annual investment in training into the \$300 billion range! More efficient learning environments increase training cost effectiveness by reducing instructional time, improving training outcomes, or both.

Psychological work demands are growing in the 21st Century. Whether you call it info glut or data delirium, information overload has gotten so bad that it's led to a new form of psychological stress called Information Fatigue Syndrome. A study from the University of California at Berkeley reports that the amount of new information created in the year 2002 disseminated in print, film, magnetic, and optical storage media equaled five exabytes (Lyman & Varian, 2003). Five exabytes is equivalent to the information contained in half a million libraries the size of the U.S. Library of Congress print collection, which exceeds nineteen million books!

Information overload erodes the quality of work. For example, primary care physicians cited information overload as a major cause of difficulties practitioners experience in diagnosing and managing heart failure (Fuat, Hungin, & Murphy, 2003). Not only is the sheer amount of information growing, but so also are the complexity and number of tasks many workers must juggle. More information and more complex tasks demand greater skills, which require more training. At the same time, organizations want to save costs by reducing time spent in training programs. These economic and psychological pressures call for efficient training environments—environments that are proven to work in harmony with the strengths and limitations of human learning processes.

## What Is Cognitive Load Theory?

As instructional professionals, many of you have probably heard of the “magical number  $7 \pm 2$ ” items of information, first published by George Miller in 1956. According to this guideline, our cognitive system can only process  $7 \pm 2$  items at one time. Once we exceed those limits, our thinking and learning processes bog down. Based on research conducted over the past twenty-five years, a growing international contingent of instructional scientists has expanded and refined the rule of  $7 \pm 2$  into a comprehensive set of instructional principles called *cognitive load theory*.

### A Definition of Cognitive Load Theory

Cognitive load theory is a universal set of learning principles that are proven to result in efficient instructional environments as a consequence of leveraging human cognitive learning processes.

- 1. Cognitive Load Theory Is Universal.** Cognitive load theory applies to all types of content, all delivery media, and all learners. Because cognitive load theory addresses how to use fundamental tools of training—text, visuals, and audio—it applies to everything from technical content to soft skills as well as to all delivery platforms from print to e-learning. Because of its universality, whether you are a classroom instructor or developer of

training materials for workbooks or computers, cognitive load theory applies to you.

**2. Cognitive Load Theory Offers Principles and Related Instructional Guidelines.**

Unlike many general educational theories, cognitive load theory offers principles that lead to very specific guidelines that all instructional professionals can implement. Throughout the chapters in this book we offer more than twenty-five specific guidelines for best ways to design, develop, and present training. Some of these guidelines are likely to be familiar methods that you may have used for years. Other guidelines, however, will be new—some even counter to prevailing instructional practice.

**3. Cognitive Load Theory Is Evidence-Based.** Cognitive load theory is based on dozens of controlled experimental research studies. Throughout the chapters we summarize some of the experiments and show you the results. Because so much training advice is not based on evidence, we feel it is important for you to have the opportunity to review at least some of the research that supports cognitive load theory. For more details, we offer recommended readings, many of which are original research reports. In Chapter 13, John Sweller, originator of cognitive load theory, writes a personal perspective of how cognitive load theory started and has evolved during the last twenty-five years.

**4. Cognitive Load Theory Leads to Efficient Learning.** Efficient instructional environments lead to faster learning, better learning, or both. The scientists who have worked on cognitive load theory have created a metric for quantifying efficiency as well as an efficiency graph for display and visual comparison of lesson efficiencies. Since you will see research data displayed on the efficiency graph throughout the book, we define and illustrate this metric and graph in this chapter.

**5. Cognitive Load Theory Leverages Human Cognitive Learning Processes.** Learning environments based on cognitive load theory minimize wasted mental resources and instead put those limited mental resources to work in ways proven to maximize learning. Because cognitive load theory is grounded in human learning processes, you will not only gain a set of proven instructional guidelines, but you will also understand why those guidelines work. Based on

this understanding, you can readily adapt them to your own instructional settings. You can also explain the basis for your instructional recommendations to your colleagues and clients. As an incidental benefit, you should also gain insights into your own cognitive processes!

## Types of Cognitive Load

Some forms of cognitive load are useful, while others waste mental resources. Your goal during training is to minimize wasteful forms of cognitive load and maximize the useful forms. The three main types of cognitive load you must consider in your training program are *intrinsic load*, *germane load*, and *extraneous load*. Since total mental capacity is limited, you will need to balance these three forms of load to maximize learning efficiency.

### Intrinsic Load

Intrinsic load is the mental work imposed by the complexity of the content in your lessons and is primarily determined by your instructional goals. For example, in Figure 1.1 we show a practice assignment from an e-lesson on

**Figure 1.1. An Assignment in an Excel Lesson That Imposes Moderate Intrinsic Cognitive Load.**

From the CD Virtual Classroom Example.

The screenshot shows a Microsoft Excel spreadsheet with the following data:

	A	B	C	D	E
2					
3		Angela	Bruce	Dave	Je
4	Hourly Wage	\$7.00	\$7.00	\$6.75	
5	Hours Worked	20	10	15	
6	Base Salary				
7	Bonus		\$50.00		
8	Deductions				
9	Employee Purchase	\$100.00			
10	Total				
11	<b>Operators:</b>				
12	+ - * /				
13					
14	<b>Assignment 2:</b>				
15	Calculate Angela's Base Salary				

The spreadsheet also includes a task assignment box in the lower-left quadrant with the text: "Assignment 2: Calculate Angela's Base Salary".

Excel® formulas drawn from our demonstration lesson on the CD. To perform this task, the learner must coordinate at least seven steps, including locating the correct spreadsheet row, locating the correct spreadsheet column, combining these to locate the correct spreadsheet cell in which to input a formula, selecting that cell with the mouse, constructing the correct formula by applying Excel format rules (which, depending on the formula, may involve many steps), typing the formula in the cell, and pressing the enter key. For someone new to Excel, this is a complex task because it requires the coordination of multiple mental and physical components. In cognitive load terminology, we would say that this assignment imposes a moderately high intrinsic load because it involves a high amount of *element interactivity*.

Element interactivity simply means that several knowledge elements must be coordinated in memory to accomplish the task. Some learning tasks are low in element interactivity because they can be accomplished in a serial rather than coordinated fashion. For example, when studying a foreign language, learning some types of vocabulary is relatively low in element interactivity because each word can be memorized independently of other words.

However, when you start to construct sentences, element interactivity jumps dramatically. When composing sentences you need to consider not only the meaning of several words but also the grammar and syntax rules that must be applied to sequence and parse the words correctly. All of these elements must be coordinated simultaneously to produce a correct sentence.

If your task is to respond verbally to a question posed in a new foreign language, the mental load is even greater. Ask any new foreign language student about the amount of mental load he or she experiences during early conversational practice! To respond verbally, the student must first interpret the question, then compose an answer by selecting the correct words and applying grammar rules, and finally pronounce the words correctly—all within a relatively short amount of time.

Intrinsic cognitive load is determined primarily by the knowledge and skills associated with your instructional objective. Although you cannot directly alter the inherent intrinsic load of your instructional content, you can manage the intrinsic load of any given lesson by decomposing complex

tasks into a series of prerequisite tasks and supporting knowledge distributed over a series of topics or lessons. This is what instructional professionals do as they create outlines of their courses and lessons. As a byproduct of segmenting and sequencing content into a series of instructional events, instructors manage intrinsic cognitive load. In Chapter 7 we summarize guidelines and evidence for best ways to manage intrinsic cognitive load through course and lesson design decisions.

## Germane (Relevant) Load

Germane cognitive load is mental work imposed by instructional activities that benefit the instructional goal. For example, learners in an Excel spreadsheet class will have different work requirements for using spreadsheets. Some students will need to construct spreadsheets as the basis for regular income and expense reports. Other students will use spreadsheets to calculate compensation that factors in taxes, commissions, bonuses, and deductions. To accomplish such diverse goals, during training, the learners will need to build a robust set of skills that they can apply to various types of spreadsheets with different data sets when they return to their work assignments. To build this flexible skill set, instructional examples should incorporate different calculation goals and data values. For example, in Figure 1.1 the learner practices a compensation calculation. Other examples in the same lesson involve profit, inventory, and sales scenarios.

Of course, learning would be easier if all of the examples used a single type of spreadsheet with similar data. However, the skills that emerge from a more homogenous set of examples have been proven to be much more limited than skills built from a diverse set of examples. By studying diverse context examples and assignments, learners end up with a much broader repertoire of spreadsheet skills applicable to many work situations.

The extra mental load imposed by this diversity is an example of germane cognitive load. Diversity in examples adds cognitive load in the service of the instructional goal. Think of germane load as relevant load imposed by instructional methods that lead to a better learning outcome. Chapter 9 is devoted entirely to instructional guidelines that add germane load.

## Extraneous (Irrelevant) Load

Extraneous cognitive load is the main form of load discussed in this book because it is always under your control as the instructor or course developer. Extraneous load imposes mental work that is irrelevant to the learning goal and consequently wastes limited mental resources. Those wasted resources drain mental capacity that could be used for germane load. As an example, take a look at Figure 1.2. It's a screen taken from our overloaded Excel CD demonstration lesson on how to construct formulas.

A number of features in this lesson waste limited mental capacity. For example, note that the words in the example are narrated and are also visible in text in the box located in the lower right corner of the screen. This design taxes mental resources in two unproductive ways. First, the learner must expend mental effort integrating the text in the lower right-hand corner

**Figure 1.2. A Screen from a Lesson on Excel with Many Sources of Extraneous Cognitive Load.**

From the Overloaded Web-Based Lesson on the CD.

**Formulas in Excel**

Audio:  
Barb has entered her sales revenue and her overhead for last year into the spreadsheet. The first thing that Barb would like to know is how much profit she made for each month last year.

Month	January	February	March	April
Sales in thousands of dollars	\$50,000	\$45,000	\$46,000	\$51,000
Overhead in thousands of dollars	\$10,000	\$10,000	\$10,000	\$10,000

**Did You Know?**  
The term "profit" comes from the Greek word "profitus" which means to gain or obtain through investment.

Barb has entered her sales revenue and her overhead for last year into this spreadsheet. The first thing that Barb would like to know is how much profit she made for each month last year.

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with the visual portion of the spreadsheet referenced by the text. Second, the learner must expend mental effort to coordinate the words presented in two modes: visually in the text and aurally in the narration. The information in the lower left hand “Did you Know” box is another source of extraneous cognitive load, since it distracts the learner from the lesson objective.

There are many other cognitive load violations in this lesson that we will discuss throughout the book. The poor design of this instructional product imposes extraneous cognitive load that drains cognitive resources needed to achieve the learning objective. The result of inefficient training programs with many extraneous sources of cognitive load is longer times to learn, poorer learning outcomes, or both. Think of extraneous cognitive load as irrelevant load.

## Balancing Mental Load in Your Training

Intrinsic, germane, and extraneous forms of cognitive load are additive. If your training program includes content that is complex, it is high in intrinsic load. If your program includes design elements that add extraneous load as well, there may be very little capacity left for germane load. Your training program will be inefficient. Consequently the learners will take longer to acquire the intended skills and/or they will not achieve the learning objective to the desired standard. To create efficient instruction, you must maximize germane load and minimize extraneous sources of load. While you usually cannot control the intrinsic load associated with the learning goals, you can manage it by segmenting and sequencing content in ways that optimize the amount of element interactivity required at any one time.

The chapters in Part II focus on ways to reduce extraneous cognitive load by: (1) optimizing the use of visual and auditory presentation modes; (2) supporting learner attention; and (3) reducing the amount of information that must be processed in memory. By minimizing extraneous load, you free limited cognitive capacity for relevant or germane load imposed by instructional techniques that serve the learning objectives. In Part III we focus on techniques that add germane load to your training.

## No Yellow Brick Road: The Relativity of Cognitive Load

Dorothy was lucky because there was a single well-defined path that led to the Emerald City. However, we will see that the path to efficiency in training is not always so straightforward. Cognitive load depends on the interaction of three components: the learning goal and its associated content, the learner's prior knowledge, and the instructional environment.

As we discussed in the previous section, intrinsic cognitive load can be high or low, depending on the amount of element interactivity required to accomplish a task. Learning outcomes that require coordination among multiple content elements will result in greater cognitive load than less complex tasks. Research shows that many of the cognitive load techniques that reduce extraneous load improve efficiency in the learning of *complex tasks only*. Low complexity content will not demand a great deal of mental resources. Therefore, learning of low complexity tasks is not impeded by extraneous cognitive load. In contrast, when tasks are complex, using techniques that minimize extraneous load improves learning efficiency. Therefore, a general guideline for achieving efficiency in learning is to minimize extraneous cognitive load in your instructional materials when learning tasks are complex.

But what is complexity? Complexity is of course relative to the performer. Indeed, we really can only define complexity in conjunction with expertise. Landing an airplane does not impose much load on an experienced pilot. However, it's an overwhelming task the first few times a novice tries it. For an experienced pilot, nothing associated with routine flying is complex. For a learner, almost everything is complex. Answering a simple question in Italian requires minimal effort by a Milanese but imposes heavy demands on mental resources from the recent learner of Italian visiting Milan for the first time.

Experts have a large skill repertoire in memory based on years of practice that allows them to effortlessly perform tasks that are overwhelming to a novice. As a result, we need to expand our general guideline for achieving efficiency in learning as follows: Avoid extraneous cognitive load when lessons involve complex content *and the learners are novices*. As we will see in Chapter 10, the techniques used to minimize extraneous load are not

needed by learners with greater prior knowledge. In fact, *many of them actually impede their learning!* You will need to change your instructional strategies as your learners develop expertise during training. In Part IV we show you how.

## Cognitive Load Theory and Human Learning

The guidelines of cognitive load theory result in more efficient learning because they exploit the limits and strengths of human learning processes. Our psychological architecture includes two main memory systems. One, called *working memory*, has a very limited capacity but is the active processing center of our brain. The rule that we cannot remember more than  $7 \pm 2$  items applies to the limited capacity of working memory. Although its capacity is limited, working memory is the site of our thinking and learning processes.

Another memory system, called *long-term memory*, has a huge capacity but is primarily a storage repository. Long-term memory cannot engage in thinking or learning processes, although, as we will see in Chapter 2, it can have a large effect on thinking and problem solving.

These two memory systems work together. As learning takes place in working memory, the new knowledge and skills are stored in long-term memory. As we gain expertise in a domain, our knowledge repository in long-term memory expands. That knowledge repository in turn allows working memory to function more efficiently in ways we will discuss in Chapter 2. As a result of the knowledge stored in long-term memory, working memory can deal with much more information, and the risks of cognitive load during learning are much lower. That's why learners with greater prior knowledge are not subject to the negative effects of instructional methods that impose extraneous load on novice learners.

## Evidence-Based Practice

The training profession has been shaped by fad and folk wisdom more than by scientific evidence of what actually works (Clark, in press). Whether it be discovery learning, edutainment, or learning styles, our training programs

are often the victims of various fads that at best waste time and resources and at worst are counterproductive to learning. Fortunately, we see some strong signals that policy makers are looking for valid research to guide instructional decisions. For the first time in history, in 1998 the U.S. Department of Education made school funding contingent on the use of funds for programs based on “proven, comprehensive reform models.” The No Child Left Behind Act mentions scientifically based research over one hundred times. Paragraph A Section 9109 defines scientific research as: “the application of rigorous, systematic, and objective procedures to obtain reliable and valid knowledge relevant to education activities and programs which includes research that is evaluated using experimental or quasi-experimental designs preferably with random assignment.”

Organizations that collectively invest billions in training programs are also seeking instructional methods that are proven to work. Evidence-based practice means grounding decisions about the development and deployment of learning programs on the basis of valid evidence—not fads, fables, or folk wisdom.

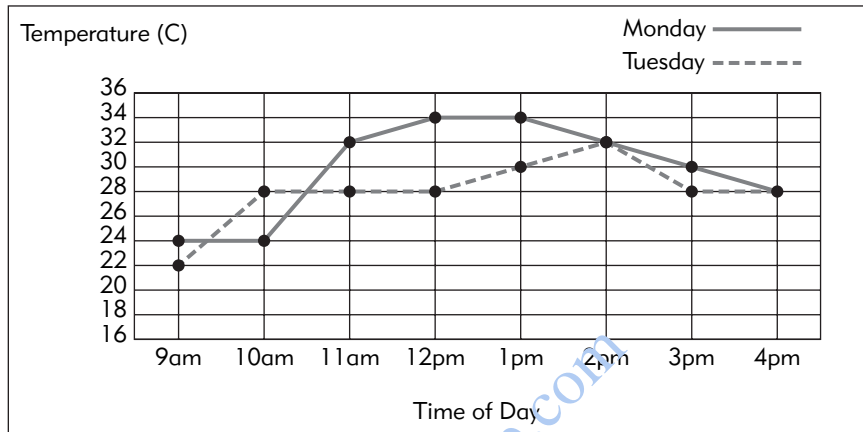
## Evidence for Cognitive Load Theory

Cognitive load theory is based on dozens of experiments conducted over the past twenty-five years by instructional scientists in Australia, Europe, and the United States. All of the research we summarize uses random assignment of participants to an experimental lesson and a comparison lesson. After a study period, the participants rate the amount of effort they invested while studying the lesson and take a test to measure learning outcomes. These two measures—invested mental effort and learning—are combined in an efficiency metric that we describe later in the chapter.

As cognitive load theory evolved, experiments were designed to measure the effects of cognitive load management methods under different conditions. Researchers compared lessons with and without cognitive load management techniques that included both high and low complexity content. For example, a study reported by Leahy, Chandler, and Sweller (2003) compared audio and text explanations of the temperature line graph shown in Figure 1.3. The test included some easy questions such as “How can you

**Figure 1.3. A Graph of Temperature Changes over Time.**

From Leahy, Chandler, and Sweller, 2003.



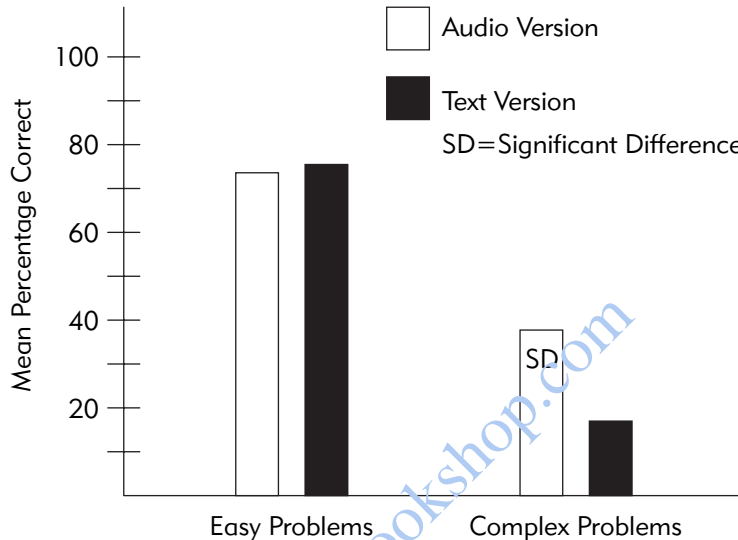
recognize zero average rate of change just by looking at the graph?” as well as some complex questions such as “What is the average rate of change between 11:00 A.M. and 1 P.M. on Tuesday?” As you can see in Figure 1.4, the lesson that explained the graph with audio narration resulted in better learning of *complex questions only*. For easier tasks, there was no difference between the audio and text versions. We conclude from this study that a textual rather than an audio explanation of a graphic can impose an extraneous cognitive load that leads to depressed learning of complex tasks. We discuss this study in greater detail in Chapter 4.

## About the Numbers

As you read, you will find summaries of research experiments like the one mentioned in the preceding paragraph that support our guidelines. For example, in Figure 1.4 you can see that, for complex tasks, the audio narrated version resulted in learning outcomes that were *significantly different* from the outcomes from the text version. *Statistical significance* means that the outcome differences are unlikely to have occurred by chance alone. But statistical significance does not necessarily mean that the results have practical implications. A statistically significant result may in fact represent only a very small

**Figure 1.4. Audio Explanations Result in Better Achievement Than Textual Explanations on Complex Questions.**

Based on data from Leahy, Chandler, and Sweller (2003).



outcome difference that is not especially relevant from a practical perspective. *Practical significance*, also known as *clinical significance*, can be better judged by a statistic called *effect size*. Effect size is a relatively recently reported statistic and you will see it often reported in research published after 2000. When available, we have included effect size data in our research summaries. As a general guideline, effect sizes less than or equal to .30 are considered small and are of negligible practical importance. Effect sizes around .50 are considered medium and are of moderate practical importance. Finally, effect sizes of .80 or higher are large and are of crucial practical importance. See the Appendix in the back of the book for more details on how effect sizes are calculated.

## Limits of Research

Any one experiment—even one with a high effect size—is likely to have limited applicability to your instructional environment because the context of the experimental conditions are different from your situation. Some

factors for you to consider with respect to any experiment include the age and prior knowledge of the learners, the content and length of the lessons, the type of assessment used to measure learning, as well as whether learning was measured immediately and/or sometime after the instructional event.

The good news about cognitive load theory is that so many experiments have been done that many of the guidelines we offer have been demonstrated in diverse environments. For example, Table 1.1 summarizes over sixteen studies that replicate the result shown in Figure 1.4—that audio explanations of visuals lead to better learning than text explanations of visuals. This guideline is called the *modality principle*. As you can see in Table 1.1, the modality principle has been demonstrated in controlled experiments using fourth graders and college students in lessons on geometry, electrical testing, and botany that lasted from just a few seconds to approximately half an hour. Most of the experiments measured different forms of learning, including recall of lesson content as well as application of that content to perform a task or solve a problem. As a result of the many diverse conditions in which the modality effect has been demonstrated, you can feel confident to use audio to explain visuals in many instructional situations summarized in Chapter 4.

In contrast to the modality effect, some of the guidelines we offer are more recent and therefore do not yet have a large number of experiments to support them. You will need to attend to the details of those experiments to infer to what extent the results are likely to apply to your setting and/or wait until more evidence accumulates.

## Quantifying Efficiency

Fundamentally, cognitive load theory is about efficiency. Cognitive load theory defines efficiency in terms of two variables: learner performance and learner mental effort. Instructional environments that result in higher learning outcomes with less mental effort are more efficient than environments that lead to lower outcomes with greater mental effort. Instructional scientists use an efficiency metric to quantify the efficiency of an instructional product.

**Table 1.1. A Summary of Experiments Demonstrating a Modality Effect.**

<i>Date/Research Team</i>	<i>Learner Population</i>	<i>Lesson Topic</i>	<i>Lesson Length</i>	<i>Outcome Measures</i>
1995—Mousavi et al., Expt 1	8th graders/ Australian	Geometry examples	Learner determined; up to 5 minutes per example on text and time to listen to audio twice	Scores on similar and different geometry problems
1995—Mousavi et al., Expt 2	8th graders/ Australian	Geometry examples	151 and 157 seconds for each example	Scores on similar and different geometry problems
1995—Mousavi et al., Expt 3	8th graders/ Australian	Geometry examples	Varied by treatment	Learning time, testing time, scores on similar and different geometry problems
1995—Mousavi et al., Expt 5	8th graders/ Australian	Geometry examples	Varied by treatment	Test solution times
1995—Mousavi et al., Expt 6	4th graders/ Australian	Geometry examples	55 seconds up to 3 minutes per example	Learning time and test solution times
1997—Tindall-Ford et al., Expt 1	Trade apprentices/ Australian	How to conduct electrical tests	5 minutes	Recognition and application
1997—Tindall Ford et al., Expt 2	Trade apprentices/ Australian	How to interpret an electrical table	100 seconds and 170 seconds	Recognition, application, and efficiency
1997—Tindall Ford et al., Expt 3	Trade apprentices/ Australian	Electrical symbol identification and how to interpret electrical circuit diagram	Approximately 3 minutes	Recall and application, test solution times, efficiency

**Table 1.1. (Continued)**

<i>Date/Research Team</i>	<i>Learner Population</i>	<i>Lesson Topic</i>	<i>Lesson Length</i>	<i>Outcome Measures</i>
1998—Mayer & Moreno, Expt 1	College students/U.S.	How lightning forms	140 seconds	Retention, recognition, application
1998—Mayer & Moreno, Expt 2	College students/U.S.	How car brakes work	45 seconds	Recall, recognition, application
2001—Moreno et al., Expt 1	College students/U.S.	Botany concepts/ game format with agent	25 minutes	Recall and application
2001—Moreno et al., Expt 2	7th graders/ U.S.	Botany concepts/ game format with agent	Self-paced, up to 40 minutes	Recall and application
2001—Moreno et al., Expt 4	College students/U.S.	Botany concepts/ game format with agent	Self-paced, 24–28 minutes	Recall and application
2001—Moreno et al., Expt 5	College students/U.S.	Botany concepts/ game format with agent	Self-paced, 24–28 minutes	Recall and application
2002—Craig et al., Expt 2	College students/U.S.	How lightning works explained by agent	180 seconds	Recall, recognition, application
2003—Leahy et al., Expt 1	5th graders/ Australian	Interpretation of a line graph	No time limit and 185 seconds	Recognition, application
2003—Mayer et al., Expt 1	College students/U.S.	How an electric motor works	Approximately 20 minutes	Application

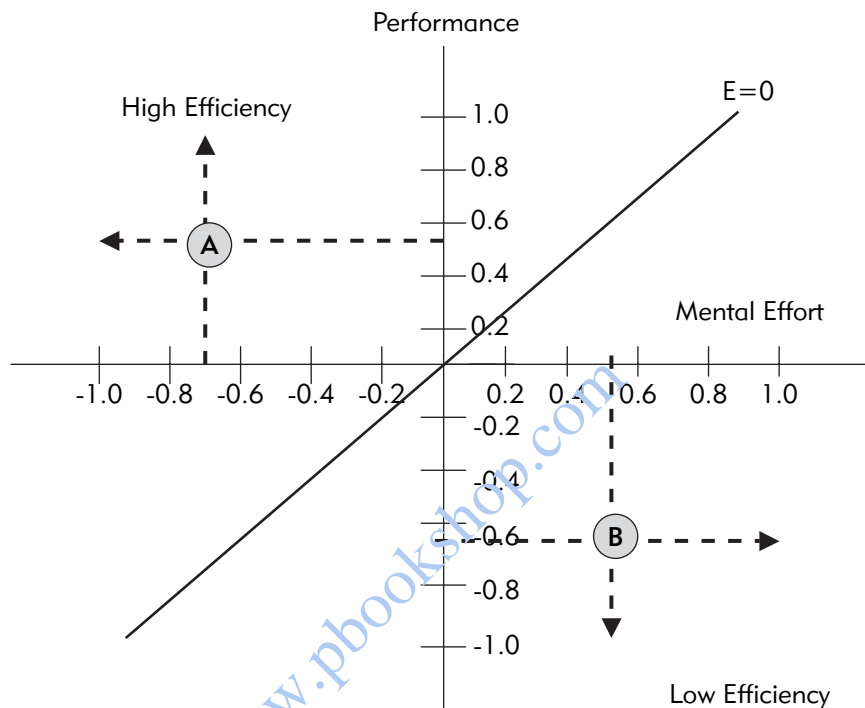
Conceptually, the efficiency metric is calculated by subtracting mental load (ML) from performance (P) outcomes. We express this mathematically as  $E = P - ML$ . When performance is greater than mental load, the efficiency value is positive. When performance is lower than mental load, the efficiency value is negative.

Performance is most often measured by a test taken at the end of the lesson. Sometimes however, performance is measured by the time required to complete a lesson or a test. Mental load is most commonly measured by learner estimates of lesson difficulty. The difficulty (mental load) of a lesson is assessed using a 1 to 7 or 1 to 9 scale in which 1 indicates extremely low mental effort (very, very easy) and 7 or 9 indicates extremely high mental effort (very, very difficult). Although learner estimates of mental load are subjective, studies that have compared these ratings with other physiological or psychological measures of mental load show that they are effective and are the most pragmatic way to assess mental effort. For a detailed technical discussion of measurement of mental effort, see the paper by Paas, Tuovinen, Tabbers, and Van Gerven (2003).

## The Efficiency Graph

To visually represent the efficiency metric, instructional scientists use an efficiency graph like the one shown in Figure 1.5. Mental effort is plotted on the horizontal axis with higher values to the right of the vertical line and lower values to the left. Performance is plotted on the vertical axis with higher values above the horizontal line and lower values below it. As you can see in Figure 1.5, the efficiency value represented by point A is high on the performance line and low on the mental effort line. High performance with low mental effort means high efficiency. The upper left quadrant of the graph is considered the high efficiency area of the graph. In contrast, point B represents an efficiency value that is low on the performance scale and high on the mental effort scale. The lower right quadrant of the graph is called the low efficiency area of the graph. For more details on the mathematics behind the efficiency value and graph, see the Appendix.

Figure 1.5. Hypothetical Efficiency Plots on the Efficiency Graph.



## The Bottom Line

In this chapter we set the stage for the book as follows:

- Cognitive load theory is an evidence-based set of universal principles and guidelines that result in more efficient learning environments.
- Efficient learning environments lead to better learning, faster learning, or both.
- Efficient learning environments balance intrinsic, germane, and extraneous sources of load.
- Cognitive load depends on the interaction among the expertise of the learner, the complexity of the content, and the instructional methods used in the training environment.

- Efficient learning environments exploit the strengths and compensate for the limits of human learning processes.
- Efficiency of an instructional product can be quantified by an efficiency metric and displayed on the efficiency graph.

## On the CD

### John Sweller Video Interview

Chapter 1: Cognitive Load Theory and Efficiency in Learning. John defines cognitive load theory and describes intrinsic, extraneous, and germane forms of cognitive load. He also discusses the evidence for cognitive load theory.

### Sample Excel e-Lessons

We have several sample lessons on the CD to illustrate applications and violations of cognitive load theory. You may want to preview them now as an introductory supplement to this book and review them as you read the various chapters in order to focus on specific techniques discussed in the chapter. The samples include:

1. An asynchronous web-based lesson that violates many cognitive load principles: Before Overloaded Excel Web-Based Lesson.
2. An asynchronous web-based lesson that applies many cognitive load principles: After Load Managed Excel Web-Based Lesson.
3. A virtual classroom (synchronous) web-based lesson that applies many cognitive load principles: Virtual Classroom Example.

In addition to each sample, there is also a commentary on the sample by John Sweller.

## COMING NEXT

Cognitive load theory works in harmony with human memory processes involved in learning. In the next chapter, we review the features of and interactions between working memory and long-term memory. We also describe

the psychological processes involved in translating lesson content into new knowledge and skills in long-term memory.

## Recommended Reading

Sweller, J. (2005). Implications of cognitive load theory for multimedia learning. In R.E. Mayer (Ed.), *Cambridge handbook of multimedia learning*. Cambridge: UK: Cambridge University Press.

<http://www.pbookshop.com>