Multimedia Learning

Second Edition

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Dedicated to Beverly

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Preface

Multimedia instruction refers to presentations involving words and pictures that are intended to foster learning. How can we design effective multimedia instruction? In this book I review twelve principles of instructional design that are based on experimental research studies carried out by my colleagues and me and that are grounded in a theory of how people learn from words and pictures, which I call the cognitive theory of multimedia learning. In short, the premise underlying this book is that the design of multimedia instruction should be based on research and grounded in theory. If you are interested in an evidenced-based and theory-grounded approach to multimedia design, then this book is for you.

For hundreds of years, verbal messages – such as lectures and printed lessons – have been the primary means of explaining ideas to learners. Although verbal learning offers a powerful tool for humans, this book explores ways of going beyond the purely verbal. An alternative to purely verbal presentations is to use multimedia presentations in which people learn from both words and pictures – a situation that I call *multimedia learning*. Recent advances in graphics technology have prompted new efforts to understand the potential of multimedia as a means of promoting human understanding – a potential that I call *the promise of multimedia learning*. In particular, my focus in this book is on whether people learn more deeply when ideas are expressed in words and pictures rather than in words alone.

Multimedia encyclopedias have become the latest addition to students' reference tools, and the Internet is full of messages that combine words and pictures. Educational games, interactive simulations, and online pedagogical agents are touted as the wave of the future in education and training. Do these multimedia forms of presentation help learners? How do people learn from words and pictures? What is the best way to design multimedia messages?

These are the kind of questions prompted by advances in information graphics technology. My premise in this book is that the answers to these questions require a program of careful, systematic research. To understand how to design multimedia messages, it is useful to understand how people learn from words and pictures.

During the past twenty years, my colleagues at Santa Barbara and I have been conducting research studies on multimedia learning. This book provides a systematic summary of what we have found. The outcome is a set of twelve principles for the design of multimedia messages and a cognitive theory of multimedia learning. In short, this book summarizes research aimed at realizing the promise of multimedia learning – that is, the potential of using words and pictures together to promote human understanding.

People learn better from words and pictures than from words alone. This is the thesis I investigate in the book you are holding. This straightforward statement is what got me started doing research on multimedia learning in the first place, and it has sustained my interest over two decades and nearly 100 experimental comparisons. In short, I began with curiosity about whether people learn more deeply from a verbal lesson when graphics are added. This curiosity prompted questions about whether value is added when we incorporate graphics into a verbal lesson, under what conditions graphics improve learning, and how graphics help people learn. If these questions also pique your interest – and you want some research-based answers – then this book is for you.

Multimedia Learning, Second Edition, is intended for anyone who is interested in the scientific underpinnings of multimedia learning. This book could be used in courses across the university, including courses in psychology, education, and computer science, as well as in specialties such as educational technology, instructional design, applied cognitive psychology, and human-computer interaction. I do not assume that the reader has any previous knowledge of psychology, education, or technology. I do assume that the reader is interested in the promise of multimedia learning – that is, in understanding how to tap the potential of multimedia messages for improving human understanding.

This book has both a theoretical and a practical orientation. On the one hand, it is aimed at those with interests in basic theory and research in the cognitive psychology of how people learn from words and pictures. On the other hand, it is aimed at those with practical interests in designing effective multimedia presentations. If you are interested in the theoretical or practical bases of multimedia learning (or a combination of the two), then this book is for you.

Writing this book has been my labor of love. I hope that you enjoy reading it as much as I have enjoyed writing it. If you have any comments or suggestions, I would like to hear from you at <mayer@psych.ucsb.edu>.

WHAT'S NEW IN THE SECOND EDITION?

The first edition of this book, published in 2001, appeared when the field of multimedia learning was still in its childhood. Since then, the research base and theoretical base of multimedia learning have continued to grow, as is indicated by numerous special issues of journals highlighting multimedia learning and numerous edited books on multimedia learning. In 2005, I had the privilege of editing *The Cambridge Handbook of Multimedia Learning*, which contains thirty-five chapters by leading multimedia researchers around the world who were charged with highlighting empirical research on multimedia design principles. Portions of this second edition of *Multimedia Learning* are based on corresponding chapters in the first edition of *Multimedia Learning* and on my four chapters (2005a, 2005b, 2005c, 2005d) in *The Cambridge Handbook of Multimedia Learning*.

There are four major changes in the second edition – concerning the growth of the research base, the growth in the number of principles, the theoretical reorganization of the principles, and the boundary conditions of the principles. First, our research base has more than doubled: In the first edition, I reported on forty-five experimental comparisons involving transfer test performance carried out by my colleagues and me, whereas in this edition that number has increased to ninety-three experimental comparisons. Second, the number of principles has increased from seven to twelve. Six original principles are retained in the second edition: coherence, redundancy, spatial contiguity, temporal contiguity, modality, and multimedia principles. Six new principles are added: signaling, segmenting, pre-training, personalization, voice, and image principles. One of the original principles – the individual differences principle – is recast as a boundary condition (i.e., the individual differences condition is the idea that design principles that are effective for beginners may not be effective for more experienced learners).

Third, the underlying theory has been expanded to incorporate the triarchic model of cognitive load, which consists of extraneous, essential, and generative cognitive processing. Correspondingly, the twelve principles of multimedia instructional design have been reorganized into three sections – reducing extraneous processing, managing essential processing, and fostering generative processing. Although the main focus of the first edition was on reducing extraneous processing, the second edition adds new foci on managing essential processing and fostering generative processing. Finally, an indication of the maturity of the field is that the second edition highlights *boundary conditions* for each principle – research-based constraints on when a principle is likely or unlikely to apply. The boundary conditions are interpreted in terms of the cognitive theory of multimedia learning, and help to both test and enrich theories of multimedia learning. A focus on boundary conditions is consistent with the idea that principles of multimedia design must be applied in light of an understanding of how people learn.

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I appreciate the excellent research environment in the Department of Psychology at the University of California, Santa Barbara, as well as the opportunity to interact with a talented group of students and professors. Throughout my thirty-three years at UCSB, I have always enjoyed the opportunity to pursue research issues that come my way. I fondly acknowledge the influence of my parents, James and Bernis Mayer, who instilled in me a love of learning and helped me appreciate the indispensable value of intellectual honesty, hard work, and boundless curiosity. Their memory is never far from my thoughts. I appreciate the interest of my children – Ken, Dave, and Sarah – who often asked, "How's the book doing?" They have brought much light into my life, as has our new grandson, Jacob. Finally, this book would not have been possible without the encouragement and support of my wife, Beverly. I am pleased to dedicate this book to her, with love.

Finally, I gratefully acknowledge the contributions of the staff at Cambridge University Press.

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Santa Barbara, CA

Section I

Introduction to Multimedia Learning

People learn better from words and pictures than from words alone. This hypothesis is the basis for the promise of multimedia learning. Multimedia instruction consists of words and pictures rather than words alone. How can we design multimedia instruction that improves learner understanding of the presented material? This is the central question addressed in this book.

Chapter 1 explores the promise of multimedia learning by offering definitions of key terms and by examining fundamental distinctions that will help you understand research on multimedia learning. A key distinction is between two goals of multimedia research – to contribute to instructional practice (i.e., the science of instruction) and to contribute to learning theory (i.e., the science of learning). The multimedia design principles presented in this book are intended to address both goals and reflect an example of what Stokes (1997, p. 73) calls "use-inspired basic research."

Chapter 2 explores the science of instruction by summarizing the methods we used to test the instructional design principles described in this book. The chapter gives you examples of the multimedia lessons and tests we used, including computer-based narrated animation, paper-based annotated illustrations, and computer-based games and simulations. I also show you how we created experimental comparisons in which we compared the test performance of a group that learned from a multimedia lesson containing a to-be-tested feature versus a group that learned from the lesson without the feature. In short, this chapter helps you see how the instructional design principles described in this book are based on evidence.

Chapter 3 explores the science of learning by summarizing a research-based theory of how people learn from words and pictures, which I call the cognitive theory of multimedia learning. The theory is based on research in cognitive science, including the ideas of dual channels, limited capacity, and active processing. The cognitive theory of multimedia learning can help you understand how we generated to-be-tested design principles and how we explained when the principles do and do not apply. In short, this chapter helps you see how the instructional design principles described in this book are grounded in theory.

1 The Promise of Multimedia Learning

Multimedia learning refers to learning from words and pictures. Multimedia instruction refers to the presentation of material using both words and pictures, with the intention of promoting learning. The case for multimedia learning rests on the premise that learners can better understand an explanation when it is presented in words and pictures than when it is presented in words alone. Multimedia messages can be based on the delivery media (e.g., amplified speaker and computer screen), presentation mode (e.g., words and pictures), or sensory modalities (e.g., auditory and visual). The design of multimedia instructional messages can be based on a technology-centered approach that focuses on the capabilities of advanced technologies or on a learner-centered approach that focuses on the nature of the human cognitive system. Multimedia learning may be viewed as response strengthening (in which multimedia environments are used as drill-and-practice systems), information acquisition (in which multimedia messages serve as information delivery vehicles), or as knowledge construction (in which multimedia messages include aids to sense-making). Three possible learning outcomes are no learning (as indicated by poor retention and poor transfer performance), rote learning (as indicated by good retention and poor transfer performance), and meaningful learning (as indicated by good retention and good transfer performance). Meaningful learning outcomes depend on the cognitive activity of the learner during learning rather than on the learner's behavioral activity during learning. The goal of basic research is to contribute a theory of learning (i.e., science of learning), whereas the goal of applied research is to derive principles of instructional design (i.e., science of instruction); merging these goals results in basic research on applied situations where the goal is to derive principles of multimedia design that are both grounded in cognitive theory and supported by empirical evidence.

Chapter Outline

WHAT IS MULTIMEDIA INSTRUCTION?

People learn better from words and pictures than from words alone. This straightforward statement summarizes the promise of multimedia learning and is the guiding thesis of this book. In short, I am intrigued by the idea that we can improve people's learning by incorporating effective graphics into verbal material. Does adding graphics to words help people learn better? What makes an effective graphic? How do people learn from words and pictures? These are the questions I address in this book – questions about what works with multimedia instruction and how people learn from multimedia instruction.

The term *multimedia instruction* means different things to different people. For some people, multimedia instruction means that a person sits at a terminal and receives a presentation consisting of on-screen text, on-screen graphics or animation, and sounds coming from the computer's speakers – as with an on-line multimedia encyclopedia. For some people, multimedia instruction means a "live" presentation in which a group of people seated in a room views images presented on one or more screens and hears music or other sounds presented via speakers. Watching a video on a TV screen can be called a multimedia experience because both images and sounds are presented. Another example of

multimedia instruction is a PowerPoint presentation in which someone presents slides from a computer projected onto a screen and talks about each one. Even low-tech environments allow for multimedia instruction, such as a "chalk and talk" presentation in which an instructor writes or draws on a blackboard (or uses an overhead projector) while presenting a lecture. Finally, the most basic form of multimedia instruction is a textbook lesson consisting of printed text and illustrations.

I define multimedia instruction as the presentation of material using both words and pictures, with the intention of promoting learning. By words, I mean that the material is presented in *verbal form* – using printed or spoken text, for example. By pictures, I mean that the material is presented in *pictorial form*, including using static graphics such as illustrations, graphs, photos, or maps, or dynamic graphics such as animations or video. This definition is broad enough to cover each of the multimedia scenarios I just described – ranging from multimedia encyclopedia entries to textbook lessons. For example, in a multimedia encyclopedia the words can be presented as on-screen text or as narration, and the pictures can be presented as graphics or animation. In a textbook, the words can be presented as printed text and the pictures as illustrations (or other kinds of graphics).

For purposes of conducting research, I have focused the definition of multimedia instruction on just two presentation formats. I have opted to limit the definition to just two formats – verbal and pictorial – because the research base in cognitive science is most relevant to this distinction. Thus, what I call multimedia learning is more accurately called dual-mode, dual-format, dual-code, or dual-channel learning.

Is *multimedia* a noun or an adjective? When used as a noun, multimedia refers to a technology for presenting material in both visual and verbal forms. In this sense, multimedia means multimedia technology – devices used to present visual and verbal material. When used as an adjective, multimedia can be used in the following contexts:

- *multimedia learning* – learning from words and pictures
- *multimedia message* or *multimedia presentation* – presentations involving words and pictures
- *multimedia instruction* (or *multimedia instructional message* or *multimedia instructional presentation*) – presentations involving words and pictures that are intended to foster learning

My focus in this book is on the design of multimedia instructional messages that promote multimedia learning.

In the remainder of this chapter, I present the case for multimedia learning, and then I examine three views of multimedia messages, two approaches to multimedia design, three metaphors of multimedia learning, three kinds of multimedia learning outcomes, two kinds of active learning, and two goals of multimedia research.

THE CASE FOR MULTIMEDIA LEARNING

An instructional message is a communication that is intended to foster learning. In presenting an instructional message to learners, instructional designers have two main formats available – words and pictures. Words include speech and printed text; pictures include static graphics (such as illustrations or photos) and dynamic graphics (such as animations or video). For hundreds of years, the major format for presenting instructional messages has been words – including lectures and books. In short, verbal modes of presentation have dominated the way we convey explanations to one another, and verbal learning has dominated education. Similarly, verbal learning has been a major focus of educational research.

The advent of computer technology has enabled an explosion in the availability of visual ways of presenting material, including large libraries of static images as well as compelling dynamic images in the form of animations and video. In light of the power of computer graphics, it may be useful to ask whether it is time to expand instructional messages beyond the purely verbal. What are the consequences of adding pictures to words? What happens when instructional messages involve both verbal and visual modes of learning? What affects the way people learn from words and pictures? In short, how can multimedia presentations foster meaningful learning? These are the kinds of questions addressed in this book.

The case for multimedia learning is based on the idea that instructional messages should be designed in light of how the human mind works. Let's assume that humans have two information processing systems – one for verbal material and one for visual material. Let's also acknowledge that the major format for presenting instructional material is verbal. The rationale for multimedia presentations – that is, presenting material in words and pictures – is that it takes advantage of the full capacity of humans for processing information. When we present material only in the verbal mode, we are ignoring the potential contribution of our capacity to process material in the visual mode as well.

Why might two channels be better than one? Two explanations are the quantitative rationale and the qualitative rationale. The quantitative rationale is that more material can be presented on two channels than on one channel – just as more traffic can travel in two lanes than in one lane. In the case of explaining how a car's braking system works, for example, the steps in the process can be presented in words or can be depicted in illustrations. Presenting both is like presenting the material twice – giving the learner twice as much exposure to the explanation. While the quantitative rationale makes sense as far as it goes, I reject it mainly because it is incomplete. In particular, I am concerned about the assumption that the verbal and visual channels are equivalent, that is, that words and pictures are simply two equivalent ways of presenting the same material.

By contrast, the qualitative rationale is that words and pictures, while qualitatively different, can complement one another and that human understanding occurs when learners are able to mentally integrate corresponding pictorial and verbal representations. As you can see, the qualitative rationale assumes that the two channels are not equivalent; words are more useful for presenting certain kinds of material – perhaps representations that are more formal and require more effort to translate – whereas pictures are more useful for presenting other kinds of material – perhaps more intuitive, more natural representations. In short, one picture is not necessarily equivalent to 1,000 words (or any number of words).

The most intriguing aspect of the qualitative rationale is that understanding occurs when learners are able to build meaningful connections between pictorial and verbal representations – such as being able to see how the words "the piston moves forward in the master cylinder" relate to the forward motion of a piston in the master cylinder in an animation of a car's braking system. In the process of trying to build connections between words and pictures, learners are able to create a deeper understanding than they could from words or pictures alone. This idea is at the heart of the cognitive theory of multimedia learning that is described in Chapter 3.

THREE VIEWS OF MULTIMEDIA MESSAGES

The term *multimedia* can be viewed in three ways – based on the devices used to deliver an instructional message (i.e., the delivery media), the representational formats used to present the instructional message (i.e., the presentation modes), or the sense modalities the learner uses to receive the instructional message (i.e., sensory modalities).

The Delivery-Media View

The most obvious view is that multimedia means the presentation of material using two or more delivery devices. The focus is on the physical system used to deliver the information – such as computer screens, amplified speakers, projectors, video recorders, blackboards, and human voice boxes. For example, in computer-based multimedia, material can be presented via the screen and via the speakers. These devices can be even further broken down by defining each window on a computer screen as a separate delivery device and each sound track coming from a speaker as a separate delivery device. In lecture-based multimedia, material can be presented via a projector onto a screen and via the lecturer's voice. In the strictest interpretation of the delivery-media view, a textbook does not constitute multimedia because the only presentation device is ink printed on paper.

What's wrong with this view of multimedia? Technically, it is the most accurate view because it focuses on the media used to present information, but psychologically, it does more to confuse the issue than to clarify it. The focus is on the devices used to present information rather than on how people learn – that is, the focus is on technology rather than on learners. Therefore, I do not take the delivery media view in this book.

The Presentation-Modes View

A second view is that multimedia means the presentation of material using two or more presentation modes. The focus is on the way that material is represented – such as through the use of words or pictures. For example, in computer-based multimedia, material can be presented verbally as on-screen text or narration and pictorially as static graphics or animation. In lecture-based multimedia, material can be presented verbally as speech and pictorially as projected graphics or video. In a textbook, material can be presented verbally as printed text and pictorially as static graphics.

This view is consistent with a learner-centered approach if we assume that learners are able to use various coding systems to represent knowledge – such as verbal and pictorial knowledge representations. Although conventional wisdom is that a picture can be converted into words and vice versa, research on mental representations suggests that verbal ways of representing knowledge may be qualitatively different from pictorial ways of representing knowledge. In short, the presentation-modes view of multimedia is consistent with a cognitive theory of learning that assumes humans have separate information-processing channels for verbal and pictorial knowledge. Paivio's (1986, 2006) dual-coding theory presents the most coherent theoretical and empirical evidence for this idea.

The Sensory-Modality View

The third view, while also consistent with a learner-centered approach, takes a somewhat different approach. According to the sensory-modalities view, multimedia means that two or more sensory systems in the learner are involved. Instead of focusing on codes used to represent knowledge in learners' information-processing systems, the sensory-modalities view focuses on the sensory receptors the learner uses to perceive the incoming material – such as the eyes and the ears. For example, in a computer-based environment an animation can be presented visually, and a narration can be presented auditorially. In a lecture scenario, the speaker's voice is processed in the auditory channel, and the slides from the projector are processed in the visual channel. In a textbook, illustrations and printed text are both processed visually, at least initially.

This view is learner-centered because it takes the learner's information-processing activity into account. Unlike the presentation-modes view, however, the sensory-modalities view is that multimedia involves presenting material that is processed visually and auditorially. This distinction is based on the idea that humans process visual images and sounds in qualitatively different ways. In short, the sensory-modalities view of multimedia is consistent with a cognitive theory of learning that assumes humans have separate information-processing channels for auditory and visual processing. Baddeley's (1999) model of working memory presents the most coherent theoretical and empirical evidence for this idea.

Table 1.1 summarizes the differences among these three views. In sum, I reject the delivery-media view because it emphasizes the technology over the learner. Both the presentation-modes view and the sensory-modalities view focus on the information-processing system of the learner and assume that humans process information in more than one channel – a proposal that I call the dual-channel assumption. However, they differ in the ways in which they conceptualize the nature of the two channels: the presentation-modes view distinguishes between separate systems for processing verbal and pictorial knowledge, whereas the sensory-modes view distinguishes between separate systems for auditory and visual processing (i.e., for processing

Table 1.1. Three Views of Multimedia

View	*Definition*	*Example*
Delivery media	Two or more delivery devices	Computer screen and amplified speakers; projector and lecturer's voice
Presentation mode	Verbal and pictorial representations	On-screen text and animation; printed text and illustrations
Sensory modality	Auditory and visual senses	Narration and animation; lecture and slides

sounds and visual images). Although my definition of multimedia learning is based on the presentation-modes view (i.e., multimedia learning involves learning from words and pictures), the sensory-modalities view (i.e., multimedia learning involves learning from auditory and visual material) is also a useful way of conceptualizing the nature of dual channels in the human information system. A goal of the research presented in this book is to examine the relative contributions of both views of multimedia. The theory of multimedia learning presented in Chapter 3 relies on the sensory-modalities view to describe early processing and the presentation-mode view to describe later processing in the learner's cognitive system.

TWO APPROACHES TO MULTIMEDIA DESIGN

Multimedia represents a potentially powerful learning technology – that is, a system for enhancing human learning. A practical goal of research on multimedia learning is to devise design principles for multimedia presentations. It is useful to distinguish between two approaches to multimedia design – a technology-centered approach and a learner-centered approach.

Technology-Centered Approaches

The most straightforward approach to multimedia design is technology-centered. Technology-centered approaches begin with the functional capabilities of multimedia and ask, "How can we use these capabilities in designing multimedia presentations?" The focus is generally on cutting-edge advances in multimedia technology, so

technology-centered designers might focus on how to incorporate multimedia into emerging communications technologies such as wireless access to the Internet or the construction of interactive multimedia representations in virtual reality. The kinds of research issues often involve media research – that is, determining which technology is most effective in presenting information. For example, a media research issue is whether students learn as well from an on-line lecture – in which the student can see a lecturer in a window on the computer screen – as from a live lecture – in which the student is actually sitting in a classroom.

What's wrong with technology-centered approaches? A review of educational technologies of the twentieth century shows that the technology-centered approach generally fails to lead to lasting improvements in education (Cuban, 1986, 2001). For example, when the motion picture was invented in the early twentieth century hopes were high that this visual technology would improve education. In 1922, the famous inventor Thomas Edison predicted that "the motion picture is destined to revolutionize our educational system and that in a few years it will supplant largely, if not entirely, the use of textbooks" (cited in Cuban, 1986, p. 9). Like current claims for the power of visual media, Edison proclaimed that "it is possible to teach every branch of human knowledge with the motion picture" (cited in Cuban, 1986, p. 11). In spite of the grand predictions, a review of educational technology reveals that "most teachers used films infrequently in their classrooms" (Cuban, 1986, p. 17). From our vantage point beyond the close of the twentieth century, it is clear that the predicted educational revolution in which movies would replace books has failed to materialize.

Consider another disappointing example that may remind you of current claims for the educational potential of online learning. In 1932, Benjamin Darrow, founder of the Ohio School of the Air, proclaimed that radio could "bring the world to the classroom, to make universally available the services of the finest teachers, the inspiration of the greatest leaders . . ." (cited in Cuban, 1986, p. 19). His colleague William Levenson, the director of the Ohio School of the Air, predicted in 1945 that a "radio receiver will be as common in the classroom as the blackboard" and "radio instruction will be integrated into school life" (cited in Cuban, 1986, p. 19). As we rush to wire our schools for access to the educational content of the Internet, it is humbling to recognize what happened to a similarly motivated movement for radio: "Radio has not been accepted as a full-fledged member of the educational community" (Cuban, 1986, p. 24).

Third, consider the sad history of educational television – a technology that combined the visual power of the motion picture with the worldwide coverage of radio. By the 1950s, educational television was being touted as a way to create a "continental classroom" that would provide access to "richer education at less cost" (Cuban, 1986, p. 33). Yet a review shows that teachers used television infrequently if at all (Cuban, 1986).

Finally, consider the most widely acclaimed technological accomplishment of the twentieth century – computers. The technology that supports computers is different from that of film, radio, and television, but the grand promises to revolutionize education are the same. Like current claims for the mind-enhancing power of computer technology, during the 1960s it was predicted that computer tutoring machines would eventually replace teachers. The first large-scale implementation occurred under the banner of computer-assisted instruction (CAI), in which computers presented short frames, solicited a response from the learner, and provided feedback to the learner. In spite of a large financial investment to support CAI, sound evaluations showed that the two largest computer-based systems in the 1970s – PLATO and TICCIT – failed to produce better learning than traditional teacher-led instruction (Cognition and Technology Group at Vanderbilt, 1996).

What can we learn from the humbling history of the twentieth century's great educational technologies? Although different technologies underlie film, radio, television, and computer-assisted instruction, they all produced the same cycle. First, they began with grand promises about how the technology would revolutionize education. Second, there was an initial rush to implement the cutting-edge technology in schools. Third, from the perspective of a few decades later it became clear that the hopes and expectations were largely unmet.

What went wrong with these technologies that seemed poised to tap the potential of visual and worldwide learning? I attribute the disappointing results to the technology-centered approach taken by the promoters. Instead of adapting technology to fit the needs of human learners, humans were forced to adapt to the demands of cutting-edge technologies. The driving force behind the implementations was the power of the technology rather than an interest in promoting human cognition. The focus was on giving people access to the latest technology rather than on helping people to learn through the aid of technology.

Are we about to replicate the cycle of high expectations, large-scale implementation, and disappointing results in the realm of multimedia technology? In my opinion, the answer to that question depends on whether or not we continue to take a technology-centered approach.

When we ask, "What can we do with multimedia?" and when our goal is to "provide access to technology," we are taking a technology-centered approach with a 100-year history of failure.

Learner-Centered Approaches

Learner-centered approaches offer an important alternative to technology-centered approaches. Learner-centered approaches begin with an understanding of how the human mind works and ask, "How can we adapt multimedia to enhance human learning?" The focus is on using multimedia technology as an aid to human cognition. Research questions focus on the relation between design features and the human information-processing system – for example, comparing multimedia designs that place light or heavy loads on the learner's visual information-processing channel. The premise underlying the learner-centered approach is that multimedia designs that are consistent with the way the human mind works are more effective in fostering learning than those that are not. This premise is the central theme of Chapter 3, which lays out a cognitive theory of multimedia learning.

Norman (1993, p. xi) eloquently makes the case for a learner-centered approach to technology design, which he refers to as human-centered technology: "Today we serve technology. We need to reverse the machine-centered point of view and turn it into a person-centered point of view: Technology should serve us." Consistent with the learner-centered approach, Norman (1993, p. 3) shows how "technology can make us smart" – that is, technology can expand our cognitive capabilities. Norman (1993, p. 5) refers to tools that aid the mind as *cognitive artifacts*: "anything invented by humans for the purpose of improving thought or action counts as an artifact." Examples include mental tools such as language and arithmetic as well as physical tools such as paper and pencils; as the twentieth century's most important new cognitive artifact, computer technology represents a landmark invention that has the potential to assist human cognition in ways previously not possible.

Norman's (1993, p. 9) assessment is that "much of science and technology takes a machine-centered view of the design of machines" so that "the technology that is intended to aid human cognition ... more often interferes and confuses." By contrast, Norman's (1993, p. 12) vision of a learner-centered approach to technology design is that "technology... should complement human abilities, aid those activities for which we are poorly suited, and enhance and help develop those for which we are ideally suited." The design of multimedia technology to promote human cognition represents one exemplary component in the larger task of creating what Norman (1993, p. xii) calls "things that make us smart."

In his review of computer technology, Landauer (1995, p. 3) proclaims that "the computer and information revolution is widely predicted to be as consequential as the industrial revolution of the previous two centuries." Further, he describes two major phases in the use of computer technology – *automation* and *augmentation*. In the automation phase, computers are used to replace humans on certain tasks ranging from robots in manufacturing to imaging devices (such as CAT scans and MRIs) in medicine to computer-based switching in telecommunications. However, Landauer (1995, p. 6) observes that the automation phase "is running out of steam" because almost all of the easy-to-automate tasks have been computerized.

The second phase of computer application – augmentation – involves the use of computers to enhance human performance on various cognitively complex tasks. Augmentation involves designing computer systems "to act as assistants, aids, and power tools" (Landauer, 1995, p. 7). However, Landauer (1995, p. 7) is disappointed with progress in the augmentation phase: "It is here... that we have failed." A major challenge in making the augmentation phase work involves the learner-centered design of computer-based technologies: "They are still too hard to use" (1995, p. 7). The design of multimedia learning environments that promote meaningful human learning is an example of using computers to augment or aid human cognition – and thus one element in Landauer's augmentation phase.

The differences between the technology-centered and learner-centered approaches to multimedia design are summarized in Table 1.2. I take a learner-centered approach in this book.

THREE METAPHORS OF MULTIMEDIA LEARNING

Design decisions about the use of multimedia depend on the designer's underlying conception of learning. In this section, I examine three views of multimedia learning – *multimedia learning as response strengthening, multimedia learning as information acquisition,* and *multimedia learning as knowledge construction*. If you view multimedia learning as response strengthening, then multimedia is a drill-and-practice system. If you view multimedia learning as information acquisition, then multimedia is an information delivery system. If you view multimedia learning as knowledge construction, then multimedia is a cognitive aid.

Table 1.2. Two Approaches to Multimedia Design

Design Approach	*Starting Point*	*Goal*	*Issues*
Technology-centered	Capabilities of multimedia technology	Provide access to information	How can we use cutting-edge technology in designing multimedia presentations?
Learner-centered	How the human mind works	Aid human cognition	How can we adapt multimedia technology to aid human cognition?

Multimedia Learning as Response Strengthening

Psychology's original view of learning is the response-strengthening view, in which learning involves strengthening or weakening an association between a stimulus and a response. This view entails assumptions about the nature of what is learned, the nature of the learner, the nature of the teacher, and the goals of multimedia presentations. First, it assumes that learning is based on changes in the strength of an association between a stimulus and a response, such as learning that the stimulus "3 + 2 = _____" is associated with the response "5." Second, the learner's job is to make responses and then receive rewards and punishments, such as "right" or "wrong." Thus, the learner is a passive being who is being conditioned by being rewarded or punished for each response. Third, the teacher's job – in this case, the multimedia designer's job – is to present rewards and punishments contingent on the learner's behavior, using reward to strengthen a response or punishment to weaken it. Finally, the goal of multimedia presentations is to enable drill and practice by soliciting responses from the learner and providing reinforcement (i.e., rewards or punishment). The underlying metaphor is that of a drill-and-practice system, so multimedia is a vehicle for rewarding correct responses and punishing incorrect ones.

The response-strengthening view is based on Thorndike's (1911) classic research on how cats learn to pull a loop of string to get out of a puzzle box. Thorndike's research resulted in his famous law of effect: behaviors that are followed by satisfaction are more likely to occur in the future under the same circumstances; behaviors that are followed by dissatisfaction are less likely to occur in the future under the same circumstances. The law of effect has been a central pillar of learning theory in psychology for 100 years. Yet critics have argued that the law of effect – and the response-strengthening view on which it is based – are not necessarily wrong, but rather are somewhat limited. They may apply to how laboratory animals learn to give a response or even to carry out a procedure, but how can they account for more complex, conceptual learning? As we move from the animal learning laboratory to the study of how humans learn conceptual material in authentic tasks, other views of learning emerge in addition to the response-strengthening view.

Multimedia Learning as Information Acquisition

According to the information-acquisition view, learning involves adding information to one's memory. As with the previous view of learning, the information-acquisition view entails assumptions about the nature of what is learned, the nature of the learner, the nature of the teacher, and the goals of multimedia presentations. First, it assumes that learning is based on information – an objective item that can be moved from place to place (such as from the computer screen to the human mind). Second, the learner's job is to receive information; thus, the learner is a passive being who takes in information from the outside and stores it in memory. Third, the teacher's job is to present information. Fourth, the goal of multimedia presentations is to deliver information as efficiently as possible. The underlying metaphor is that of multimedia as a delivery system; according to this metaphor, multimedia is a vehicle for efficiently delivering information to the learner.

The information-acquisition view is sometimes called the *empty vessel view* because the learner's mind is seen as an empty container that needs to be filled by the teacher pouring in some information. Similarly, the information-acquisition view is sometimes called the *transmission view* because the teacher transmits information to be received by the learner. Finally, this is sometimes called the *commodity view* because information is seen as a commodity that can be moved from one place to another.

What's wrong with the information-acquisition view? If your goal is to help people learn isolated fragments of information, then I suppose nothing is wrong with the information-acquisition view. However, when your goal is to promote understanding of the presented material, the information-acquisition view is not very helpful. Even worse, it

conflicts with the research base on how people learn complex material (Bransford, Brown, & Cocking, 1999; Mayer, 2008a). When people are trying to understand presented material – such as a lesson on how a car's braking system works – they are not tape recorders who carefully store each word. Rather, humans focus on the meaning of presented material and interpret it in light of their prior knowledge.

Multimedia Learning as Knowledge Construction

In contrast to the information-acquisition view, the knowledge-construction view is that multimedia learning is a sense-making activity in which the learner seeks to build a coherent mental representation from the presented material. Unlike information – which is an objective commodity that can be moved from one mind to another – knowledge is personally constructed by the learner and cannot be delivered in exactly the same form from one mind to another. This is why two learners can be presented with the same multimedia message and come away with different learning outcomes. Second, according to the knowledge-construction view, the learner's job is to make sense of the presented material; thus, the learner is an active sense-maker who experiences a multimedia presentation and tries to organize and integrate the presented material into a coherent mental representation. Third, the teacher's job is to assist the learner in this sense-making process; thus, the teacher is a cognitive guide who provides needed guidance to support the learner's cognitive processing. Fourth, the goal of multimedia presentations is not only to present information, but also to provide guidance for how to process the presented information – that is, for determining what to pay attention to, how to mentally organize it, and how to relate it to prior knowledge. Finally, the underlying metaphor is that of multimedia as a helpful communicator; according to this metaphor, multimedia is a sense-making guide, that is, an aid to knowledge construction.

Table 1.3 summarizes the differences among the three views of multimedia learning. In this book, I favor a knowledge-construction view because it is more consistent with the research base on how people learn and because it is more consistent with my goal of promoting understanding of presented material. Rather than seeing the goal of multimedia presentations as exposing learners to vast quantities of information, my goal for multimedia is to help people develop [illegible] understanding of important aspects of the presented material. For example, the Cognition and Technology Group at Vanderbilt (1996) [illegible] that the conception of learning has changed from being able to

Table 1.3. *Three Metaphors of Multimedia Learning*

Metaphor	*Definition*	*Content*	*Learner*	*Teacher*	*Goal of Multimedia*
Response strengthening	Strengthening or weakening an association	Associations	Passive recipient of rewards and punishments	Dispenser of rewards and punishments	Enable drill and practice; act as a reinforcer
Information acquisition	Adding information to memory	Information	Passive information receiver	Information provider	Deliver information; act as a delivery vehicle
Knowledge construction	Building a coherent mental structure	Knowledge	Active sense-maker	Cognitive guide	Provide cognitive guidance; act as a helpful communicator

remember and repeat information to being able to find and use it. Similarly, Bransford, Brown, and Cocking (1999, p. xi) note that "in the last 30 years . . . views of how effective learning proceeds have shifted from the benefits of diligent drill and practice to focus on students' understanding and application of knowledge." In short, the knowledge-construction view offers a more useful conception of learning when the goal is to help people to understand and to be able to use what they have learned.

THREE KINDS OF MULTIMEDIA LEARNING OUTCOMES

There are two major goals of learning – *remembering* and *understanding*. Remembering is the ability to reproduce or recognize the presented material, and is assessed by retention tests. The most common retention tests are *recall* – in which learners are asked to reproduce what was presented (for example, writing down all they can remember from a lesson they read) – and *recognition* – in which learners are asked to select what was presented (as in a multiple-choice question) or judge whether a given item was presented (as in a true-false question). Thus, the major issue in retention tests involves quantity of learning – that is, how much was remembered.

Understanding is the ability to construct a coherent mental representation from the presented material; it is reflected in the ability to use the presented material in novel situations, and is assessed by transfer tests. In a transfer test, learners must solve problems that were not explicitly given in the presented material – that is, they must apply what they learned to a new situation. An example is an essay question that asks learners to generate solutions to a problem, which requires going beyond the presented material. The major issue in transfer tests involves the quality of learning – that is, how well someone can use what they have learned. The distinction between remembering and understanding is summarized in Table 1.4. My goal in this book is to promote understanding as well as retention.

Consider the following scenario. Alice turns on a computer, selects an on-line multimedia encyclopedia, and clicks on the entry for "brakes." On the screen appears a passage consisting of on-screen text; it explains the steps in the operation of a car's braking system, beginning with stepping on the brake pedal and ending with the car coming to a stop. Alice reads casually, looking at each word but hardly focusing on the material. When I ask her to explain how a car's braking system works, she performs poorly – recalling almost none of

Table 1.4. Two Goals of Multimedia Learning

Goal	*Definition*	*Test*	*Example Test Item*
Remembering	Ability to reproduce or recognize presented material	Retention	Write down all you can remember from the passage you just read.
Understanding	Ability to use presented material in novel situations	Transfer	List some ways to improve the reliability of the device you just read about.

the eight steps that were presented. When I ask her to solve some problems based on the presented material, such as diagnosing why a car's braking system might fail, she also performs poorly – generating almost no creative solutions (such as saying that a piston could be stuck or a brake line may have a hole in it). This is an example of a learning outcome that is all too familiar – *no learning*. In the case of no learning, the learner performs poorly on tests of retention and transfer. Alice lacks knowledge about the braking system.

Next, consider Brenda. She reads the same "brakes" passage as Alice, but tries hard to learn the presented material. When I ask her to write an explanation of how a car's braking system works, she performs well – recalling many of the eight steps in the passage. However, when I ask her to solve transfer problems, she performs poorly, like Alice. This is an example of another common kind of learning outcome – *rote learning*. The distinguishing pattern for rote learning outcomes is good retention and poor transfer. In this case, Brenda has acquired what can be called *fragmented knowledge* or *inert knowledge*, knowledge that can be remembered but cannot be used in new situations. In short, Brenda has acquired a collection of *factoids* – isolated bits of information.

Finally, consider a third learner, Cathy. When she clicks on "brakes," she receives a multimedia presentation consisting of the same on-screen text that Alice and Brenda saw as well as a computer-generated animation depicting the steps in the operation of a car's braking system. When I ask Cathy to write an explanation of how a car's braking system works, she performs well – recalling as many of the steps as Brenda. When I ask her to solve transfer problems, she also performs well, unlike Brenda – generating many creative solutions. Cathy's performance suggests a third kind of learning outcome – *meaningful learning*.

Table 1.5. Three Kinds of Multimedia Learning Outcomes

		Test Performance	
Learning Outcome	*Cognitive Description*	*Retention*	*Transfer*
No learning	No knowledge	Poor	Poor
Rote learning	Fragmented knowledge	Good	Poor
Meaningful learning	Integrated knowledge	Good	Good

Meaningful learning is distinguished by good transfer performance as well as good retention performance. Presumably, Cathy's knowledge is organized into an integrated representation.

The three kinds of learning outcomes are summarized in Table 1.5. My goal in this book is to examine design features of multimedia that foster meaningful learning. In particular, I focus on ways of integrating words and pictures that foster meaningful learning.

TWO KINDS OF ACTIVE LEARNING

What's the best way to promote meaningful learning outcomes? The answer rests in *active learning* – because meaningful learning outcomes occur as a result of the learner's activity during learning. However, does active learning refer to what's going on with the learner's physical behavior – such as the degree of hands-on activity – or to what's going on in the learner's mind – such as the degree of integrative cognitive processing? In short, if the goal is to foster meaningful learning outcomes, should multimedia presentations be designed mainly to prime behavioral activity or cognitive activity?

Consider the following situation. Alan is preparing for an upcoming test in meteorology. He sits in front of a computer and clicks on an interactive tutorial on lightning. The tutorial provides hands-on exercises in which he must fill in blanks by writing words. For example, on the screen appears the sentence: "Each year approximately _____ Americans are killed by lightning." He types in an answer, and the computer then provides the correct answer. In this case, Alan is behaviorally active in that he is typing answers on the keyboard, but he may not be cognitively active in that he is not encouraged to make sense of the presented material.

By contrast, consider the case of Brian, who is preparing for the same upcoming meteorology test. Like Alan, he sits in front of a computer and clicks on a tutorial about lightning; however, Brian's tutorial is a short narrated animation explaining the steps in lightning formation. As he watches and listens, Brian tries to focus on the essential steps in lightning formation and to organize them into a cause-and-effect chain. Wherever the multimedia presentation is unclear about why one step leads to another, Brian uses his prior knowledge to help create an explanation for himself – what Chi and colleagues (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Roy & Chi, 2005) call a *self-explanation*. For example, when the narration says that positively charged particles come to the surface of the earth, Brian mentally creates the explanation that opposite charges attract. In this scenario, Brian is behaviorally inactive because he simply sits in front of the computer; however, he is cognitively active because he is actively trying to make sense of the presentation.

Which type of active learning promotes meaningful learning? Research on learning shows that meaningful learning depends on the learner's cognitive activity during learning rather than on the learner's behavioral activity during learning. You might suppose that the best way to promote meaningful learning is through hands-on activity, such as a highly interactive multimedia program. However, behavioral activity per se does not guarantee cognitively active learning; it is possible to engage in hands-on activities that do not promote active cognitive processing – such as in the case of people playing some highly interactive computer games. You might suppose that presenting material to a learner is not a good way to promote active learning because the learner appears to sit passively. In some situations, your intuition would be right – presenting a long, incoherent, and boring lecture or textbook chapter is unlikely to foster meaningful learning. However, in other situations, such as the case of Brian, learners can achieve meaningful learning in a behaviorally inactive environment such as a multimedia instructional message. My point is that well-designed multimedia instructional messages can promote active cognitive processing in learners even when they seem to be behaviorally inactive.

Figure 1.1 summarizes the two kinds of active learning – behavioral activity and cognitive activity. If meaningful learning depends on active cognitive processing in the learner, then it is important to design learning experiences that prime appropriate cognitive processing. In this book I focus mainly on learning from multimedia instructional messages in which learners may appear to be behaviorally inactive but which are designed to promote active cognitive learning, as indicated

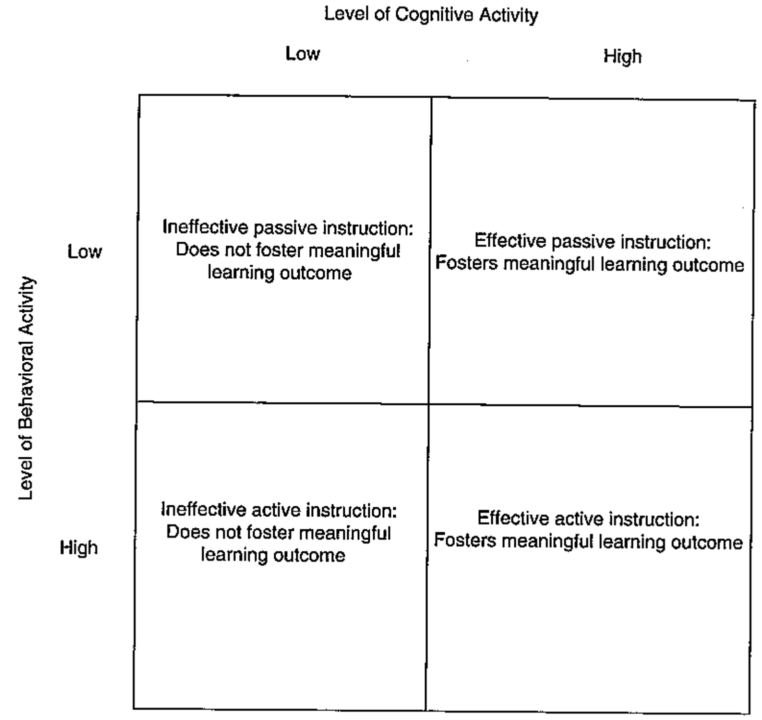

Figure 1.1. Two kinds of active learning.

in the top-right quadrant. This quadrant represents active cognitive learning based on passive instructional methods (Mayer, 2004), such as learning with some well-designed multimedia instructional messages. In addition, the bottom-right quadrant represents active cognitive learning based on active instructional methods (Mayer, 2004), such as interactive games and simulations. Some of the studies on interactive games and simulations reported in this book fall into this quadrant.

TWO GOALS OF MULTIMEDIA RESEARCH

Should you classify multimedia research as basic research or applied research? The goal of basic research is to contribute to theory – for example, a research-based explanation of how people learn (i.e., the science of learning). This goal is represented in the left-side labels of Figure 1.2, in which we ask whether the research contributes to learning

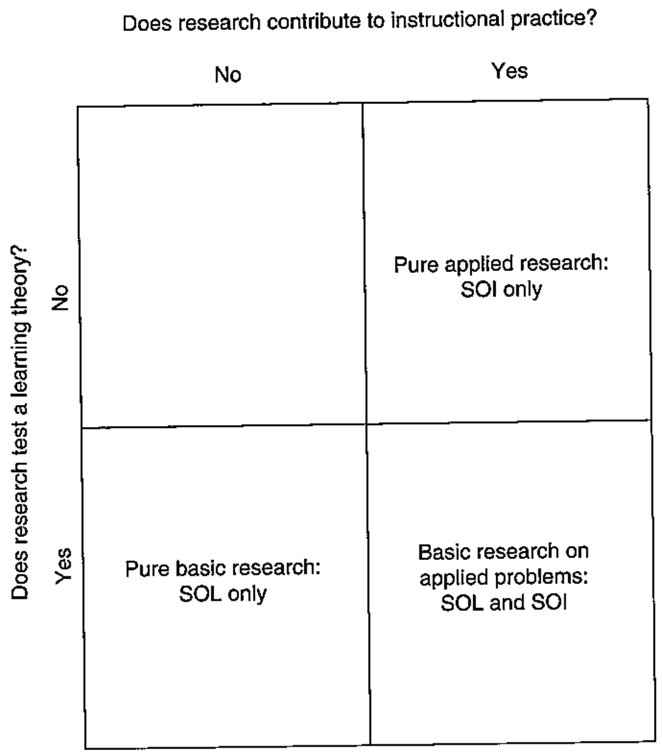

Figure 1.2. Two kinds of research goals.

theory. The bottom two quadrants contribute to theory, so I have designated them "SOL" (for science of learning). By contrast, the goal of applied research is to contribute to practice – for example, evidence-based principles for how to design effective multimedia instruction (i.e., the science of instruction). This goal is represented in the top labels of Figure 1.2, in which we ask whether the research contributes to instructional practice. The two quadrants on the right contribute to practice, so I have designated them with "SOI" (for science of instruction).

Figure 1.2 presents four quadrants based on these two kinds of research goals, and is inspired by Stokes' (1997) *Pasteur's Quadrant*. The top-left quadrant represents research that does not contribute to learning theory and does not contribute to instructional practice, and thus is not of much interest to anyone. The top-right quadrant represents research that contributes to instructional practice but not to learning theory, which is the hallmark of pure applied research.

This kind of research identifies what works in multimedia instruction, but is of limited value because we do not know how it works or under what conditions we could expect it work. The bottom-left quadrant represents research that contributes to learning theory but not to instructional practice, which is the hallmark of pure basic research. This kind of research is of limited value because it does not test the predictions of learning theory within authentic learning situations.

Finally, the bottom-right quadrant of Figure 1.2 represents research that contributes to learning theory and to instructional practice, which is the hallmark of what Stokes (1997, p. 73) calls "use-inspired basic research" or what I (Mayer, 2008c) call *basic research in applied situations*. In this kind of research, we seek to accomplish two goals – contributing to theory and contributing to practice. Use-inspired basic research challenges learning theory to explain how learning works on authentic tasks and enriches instructional practice by helping us understand the conditions under which the principles can be expected to apply. Although it is customary to view basic research and applied research as opposite ends of a pole, an alternative is to view them as goals that can overlap. In this book, I focus on research that has overlapping goals – to conduct research on multimedia principles that both contribute to learning theory and contribute to instructional practice. In summary, the answer to the question about whether multimedia research should be basic or applied is that it should be both basic and applied. When we are working in the lower-right quadrant with overlapping theoretical and practical goals, successful basic research and successful applied research are the same thing.

In Chapter 2, I focus on the science of instruction, in which I describe the research methodology we used to derive our evidence-based principles of multimedia design. In particular, Chapter 2 includes examples of some of the multimedia instructional messages we used, and overviews of our independent variables, dependent measures, and effect-size methodology. For purposes of conducting research, we have focused on just one kind of multimedia message – instruction aimed at explaining how something works – and we have restricted our studies of multimedia learning to focus on learning from words and pictures. In Chapter 3, I focus on the science of learning, in which I describe the cognitive theory of multimedia learning. In particular, Chapter 3 describes a research-based theory of how people learn from words and pictures, which inspired each of the principles of multimedia design that we tested.

SUGGESTED READINGS

Asterisk (*) indicates that a portion of this chapter was based on this publication.

Section 1 on "What Is Multimedia Instruction?"

Spector, J. M., Merrill, M. D., van Merrienboer, J., & Driscoll, M. P. (2008). *Handbook of research for educational communications and technology* (3rd ed.) New York: Erlbaum.

Mayer, R. E. (Ed.). (2005). *The Cambridge handbook of multimedia learning.* New York: Cambridge University Press.

Section 2 on "The Case for Multimedia Learning"

*Mayer, R. E. (2000). The challenge of multimedia literacy. In A. W. Pailliotet & P. B. Mosenthal (Eds.), *Reconceptualizing literacy in the new age of media, multimedia, and hypermedia* (pp. 363–376). Norwood, NJ: JAI/Ablex.

*Mayer, R. E. (2005). Introduction to multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 1–17). New York: Cambridge University Press.

Section 3 on "Three Views of Multimedia Messages"

*Mayer, R. E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist, 32,* 1–19.

Section 4 on "Two Approaches to Multimedia Design"

Cuban, L. (1986). *Teachers and machines: The classroom use of technology since 1920.* New York: Teachers College Press.

Landauer, T. K. (1995). *The trouble with computers.* Cambridge, MA: MIT Press.

*Mayer, R. E. (1999). Instructional technology. In F. T. Durso, R. S. Nickerson, R. W. Schvaneveldt, S. T. Dumais, D. S. Lindsay, & M. T. H. Chi (Eds.), *Handbook of applied cognition* (pp. 551–569). Chichester, England: Wiley.

Norman, D. A. (1993). *Things that make us smart.* Reading, MA: Addison-Wesley.

Section 5 on "Three Metaphors of Multimedia Learning"

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How people learn.* Washington, DC: National Academy Press.

*Mayer, R. E. (1992). Cognition and instruction: Their historic meeting within educational psychology. *Journal of Educational Psychology, 84,* 405–412.

Section 6 on "Three Kinds of Multimedia Learning Outcomes"

Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, R. E., & Raths, J. (2001). *A taxonomy of learning for teaching: A revision of Bloom's taxonomy of educational objectives.* New York: Addison-Wesley-Longman.

*Mayer, R. E. (2008). *Learning and instruction* (2nd ed). Upper Saddle River, NJ: Pearson Prentice Hall Merrill.

Section 7 on "Two Kinds of Active Learning"

*Mayer, R. E. (1999). Designing instruction for constructivist learning. In C. M. Reigeluth (Ed.), *Instructional design theories and models* (pp. 141–159). Mahwah, NJ: Erlbaum.

*Mayer, R. E. (2004). Should there be a three strikes rule against pure discover learning? The case for guided methods of instruction. *American Psychologist, 59*(1), 14–19.

Section 8 on "Two Goals of Multimedia Research"

*Mayer, R. E. (2008). Applying the science of learning: Evidence-based principles of multimedia instruction. *American Psychologist, 63*(8), 760–769.

Stokes, D. E. (1997). *Pasteur's quadrant: Basic science and technological innovation.* Washington, DC: Brookings Institution Press.