

Multimedia Learning

Third Edition

Advances in computer graphic technologies have inspired new efforts to understand the potential of multimedia instruction as a means of promoting human learning. In *Multimedia Learning, Third Edition*, Richard E. Mayer takes an evidence-based approach to improving education using well-designed multimedia instruction. He reviews 15 principles of multimedia instructional design that are based on more than 200 experimental research studies and grounded in a cognitive theory of how people learn from words and graphics. The result is the latest instalment of what Mayer calls the Cognitive Theory of Multimedia Learning, a theory introduced in previous editions of *Multimedia Learning* and in *The Cambridge Handbook of Multimedia Learning, Second Edition*. This edition provides an up-to-date and systematic summary of research studies on multimedia learning, supplemented with complementary evidence from around the globe. It is well-suited to graduate and undergraduate courses in psychology, education, computer science, communication, instructional design, and game design.

Richard E. Mayer is Distinguished Professor of Psychological and Brain Sciences at the University of California, Santa Barbara, USA. He served as President of the Division of Educational Psychology of the American Psychological Association and Vice President of the American Educational Research Association for the Division of Learning and Instruction.

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THIRD EDITION

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Dedicated to Beverly

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Preface

What This Book Is About

Multimedia instruction refers to communications involving words and pictures that are intended to foster learning. How can we design effective multimedia instruction? In this book, I review 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 evidence and grounded in learning theory. If you are interested in an evidenced-based and theory-grounded approach to multimedia instructional design, then this book is for you.

For hundreds of years, verbal messages – such as oral 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 communications is to use multimedia communications in which people learn from both words and pictures – a situation that I call *multimedia learning*. Advances in computer-based graphics technology have prompted new efforts to understand the potential of multimedia instruction 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.

This book 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 psychology, education, and computer science; and in specialties such as educational technology, instructional design, game design, applied cognitive psychology, and human–computer interaction. I do not assume you have any previous knowledge of psychology, education, or technology. I do assume that you are 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 practical orientation. On one hand, it is aimed at readers 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 readers with practical interests in designing effective multimedia

instruction. If your interests are in the theoretical or practical bases of multimedia learning (or a combination of the two), then this book is for you.

How This Book Involves Applying the Science of Learning to Education

Across the globe a small but determined team of researchers is busily investigating how learning works, how instruction works, and how assessment works in an effort to apply the science of learning to education (Mayer, 2011). I feel privileged to play even a small part in this worthwhile effort. For more than 100 years, researchers have sought to apply the methods of science to improving education, as called for in William James' classic little book, *Talks to Teachers* (1899) and epitomized by the pioneering work of E. L. Thorndike (Thorndike, 1913).

This book reports on a more recent campaign in this 100-year effort – research on multimedia learning. In short, this book provides you with an example of the progress being made over the past three decades in one attempt to apply to the science of learning to education. If you are interested in taking an evidence-based approach to improving education, this book gives you an example based on the quest to understand how to design effective multimedia instruction.

Why I Wrote This Book

Suppose you click on an entry on “climate change” in an online encyclopedia, watch a YouTube video on how to set a new feature on your cell phone, or play a game on your tablet that teaches you about electrical circuits. In school, suppose you are assigned to view a narrated animation explaining today's topic before class, you attend a face-to-face lecture in which the instructor talks while presenting a slideshow, or you watch a recorded instructional video for review after class. These are all examples of multimedia instruction, because they all involve communications containing words and pictures intended to help you learn something. Not all multimedia instruction involves digital technology, of course. For example, when you read your textbook, you are receiving multimedia instruction in the form of printed words and graphics. If you are interested in how best to design multimedia instruction that promotes student learning, this book is for you.

The Internet is full of instructional messages that combine words and pictures. Educational games, interactive simulations, multimedia encyclopedias, instructional videos, immersive virtual reality, and online pedagogical agents are touted as the wave of the future in education and training. How can these multimedia

platforms be used to 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 answering these questions requires 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 30 years, my colleagues and I at the University of California, Santa Barbara (UCSB), have been conducting research studies on multimedia learning. This book provides a systematic summary of what we have found, supplemented with complementary evidence from around the globe. The outcome is a set of 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 has sustained my interest over three decades and more than 200 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 how best to combine graphics with words to create an effective multimedia lesson, under what conditions added graphics improve learning, and how adding graphics helps people learn. If these questions also peak your interest – and you want some research-based answers – I wrote this book for you.

What Is New in the Third Edition?

The first edition of this book, published in 2001, appeared as the field of multimedia learning was still in its childhood. In the ensuing years, the research base and theoretical base of multimedia learning continued to grow, as reflected in the second edition of this book published in 2009. Since that time, the field has matured to the point that a third edition is warranted. In the meanwhile, the development of the field was reflected in numerous special issues of journals highlighting multimedia learning, numerous edited books on multimedia learning, and a growing corpus of meta-analyses of popular multimedia design principles.

In 2005, I had the privilege of editing *The Cambridge Handbook of Multimedia Learning*, which contained 35 chapters by leading multimedia researchers from around the world who were charged with highlighting empirical research on multimedia design principles, and in 2014, I was pleased to edit the second edition,

which contained 40 per cent more pages. Portions of this third edition of *Multimedia Learning* are based on updating corresponding chapters in the second edition of *Multimedia Learning* and on my four chapters (Mayer, 2014a, 2014b; Mayer & Fiorella, 2014; Mayer & Pilegard, 2014) in *The Cambridge Handbook of Multimedia Learning: Second Edition*.

There are four major changes in the third edition of this book involving advances in addressing questions about what works, when does it work, where does it work, and how does it work. First, concerning what works, over the years our research base has grown tremendously: in the first edition published in 2001, I reported on 45 experimental comparisons involving transfer test performance carried out by my colleagues and me, whereas that number increased to 93 experimental comparisons in the second edition published in 2009 and 201 in this third edition published in 2020. Replication of results is the sign of a maturing scientific field and is recognized as a core condition of scientific research in education: “Scientific knowledge advances when findings are reproduced in a range of times and places and when findings are integrated and synthesized” (Shavelson & Towne, 2002, p. 4). The growing number of meta-analyses involving various multimedia principles is enabled by the growth in the size of the empirical research base. This growing research base allows us to draw conclusions about what works with a higher level of certainty.

Along with the growth in the number of experiments testing multimedia principles, we see an increase in the number of principles being tested. The number of principles has increased from seven in the first edition to 12 in the second edition to 15 in this third edition. Six original principles are retained from the first edition: coherence, redundancy, spatial contiguity, temporal contiguity, modality, and multimedia principles. Six new principles were added in the second edition: signaling, segmenting, pre-training, personalization, voice, and image principles. Finally, three new principles were added in this third edition: embodiment, immersion, and generative activity principles. One of the original principles – the individual differences principle – has been 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).

Overall, the first edition focused mainly on principles for reducing extraneous processing (i.e., cognitive processing that does not serve the instructional goal). The second edition mainly added new principles for managing essential processing (i.e., cognitive processing needed to acquire the essential information) and for promoting generative processing (i.e., cognitive processing aimed at making sense of the material). The third edition mainly adds new principles for promoting generative processing, that is for motivating the learner to want to exert effort to learn. Thus, the field is broadening by recognition of the role of social, affective, motivational, and metacognitive aspects of multimedia learning.

Second, concerning when does it work, a sign of maturity in our field is the increasing focus on *boundary conditions* for each principle – research-based constraints on when a principle is likely or not likely 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. This includes research on moderating variables aimed at determining whether the principle works differently for different kinds of learners (such as high-knowledge learners versus low-knowledge learners or learners in various age groups), kinds of instructional content (such as different subject areas or different levels of learning objectives), kinds of assessments (such as immediate versus delayed tests or retention versus transfer tests), or types of media (such as paper, desktop computers, tablets, or immersive virtual reality). A continuing need in this line of research is to establish replicated evidence for heavily studied boundary conditions and to develop theory-based explanations for boundary conditions.

Third, concerning where does it work, we have seen a movement away from research with paper-based media such as printed lessons to research with computer-based media such as narrated animation, narrated slideshows, instructional video, computer games and simulations, and virtual and augmented reality. However, most research still focuses on learning in short-term studies with immediate tests in laboratory environments involving college students, so a continuing need is to expand the scope of experiments to include longer-term studies with delayed tests in authentic learning and training environments.

Fourth, concerning how does it work, we have seen an increasing focus on understanding the cognitive and motivational processes during learning that support meaningful learning. This third edition includes studies aimed at testing an expanded version of the cognitive theory of multimedia learning that includes the triarchic model of cognitive load, consisting of extraneous, essential, and generative cognitive processing during learning. Although early theories focused mainly on cognitive processes in multimedia learning, there is an increasing interest in incorporating motivational and affective processes, as reflected in Moreno and Mayer's (2007) cognitive affective theory of learning with media, Mayer's (2014b) social agency theory of multimedia learning, and Plass and Kaplan's (2016) emotional design theory of learning with digital media. This third edition includes studies that begin to broaden assessment tools beyond retention tests to measure learning outcomes and questionnaires to measure learning processes. As with previous editions, all of the research reported in this book includes transfer test performance as the main assessment of learning outcome, because my focus is on meaningful learning. In addition, unlike previous editions, this edition also highlights attempts to measure cognitive processes during learning using objective

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measures such as eye-tracking, log file data, and brain-based measures such as electroencephalogram (EEG). Future work is needed to expand the use of objective measures of cognitive and motivational processes during learning including eye-tracking and EEG as well as physiological measures of emotional arousal, such as electrodermal activity (EDA) and heart-rate variability (HRV).

In short, the third edition of *Multimedia Learning* documents one of educational psychology's success stories, demonstrating the power of applying rigorous experimental research methods to the practical problems of education. The book you are holding (or viewing on your screen) helps you see that the field is growing its empirical research base in support of design principles, establishing boundary conditions for when each principle applies consistent with learning theory, broadening the context of study to include various forms of digital media, and expanding the theoretical basis to include cognitive and motivational processes during learning. In short, this book reflects the latest progress report on one quest to apply the science of learning to education, and in the process contributes both to learning theory and educational practice.

The Future

From my office on the third floor of Psychology East on the campus of the University of California, Santa Barbara, I can see the Pacific Ocean, glimmering in the morning sun. If I walk down the street to the beach, I can watch the waves roll onto the sandy beach. Each wave builds to a crest, and comes pounding to shore, dominating the area for a brief moment, until the water gathers itself together and drifts back out to be part of the next big wave. As I watch, I think to myself, educational fads can be like ocean waves. They build up, reach a crest, and inundate our schools for a while; then, they recede and regroup for the next big wave. My hope is we can break this cycle of educational fads, and build educational practices on a foundation of research evidence. Don't get me wrong, I do not have anything against waves, but I think they belong in the ocean rather than in our schools. If this book helps you to see the value of applying the science of learning to multimedia instruction, I will consider it a success.

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).

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REFERENCES

- James, W. (1958). *Talks to teachers*. New York: Norton. [Originally published in 1899.]
- Mayer, R. E. (2011). *Applying the science of learning*. Boston, MA: Pearson.
- Mayer, R. E. (2014a). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed.; pp. 43–71). New York: Cambridge University Press.
- Mayer, R. E. (2014b). Principles based on social cues in multimedia learning: Personalization, voice, image, and embodiment principles. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed.; pp. 345–368). New York: Cambridge University Press.
- Mayer, R. E., & Fiorella, L. (2014). Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity, and temporal contiguity. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed.; pp. 279–315). New York: Cambridge University Press.
- Mayer, R. E., & Pilegard, C. (2014). Principles for managing essential processing in multimedia learning: Segmenting, pretraining, and modality principles. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed.; pp. 316–344). New York: Cambridge University Press.
- Moreno, R., & Mayer, R. E. (2007). Interactive multimodal learning environments. *Educational Psychology Review*, 19, 309–326.
- Plass, J., & Kaplan, U. (2016). Emotional design in digital media for learning. In S. Y. Tettegah & M. Gartmeier (Eds), *Emotions, technology, design, and learning* (pp. 131–162). San Diego, CA: Academic Press.
- Shavelson, R. J., & Towne, L. (2002). *Scientific research in education*. Washington, DC: National Academy Press.
- Thorndike, E. L. (1913). *Educational psychology*. New York: Columbia University Press.

About the Author

Richard E. Mayer is Distinguished Professor of Psychological and Brain Sciences at the University of California, Santa Barbara. His research interests are in applying the science of learning to education, with a focus on how to help people learn in ways so they can transfer what they have learned to new situations. His research is at the intersection of cognition, instruction, and technology, with current projects on multimedia learning, computer-supported learning, learning strategies, and computer games for learning. He served as President of Division 15 (Educational Psychology) of the American Psychological Association and Vice President of the American Educational Research Association for Division C (Learning and Instruction). He is the winner of the E. L. Thorndike Award for career achievement in educational psychology, the Sylvia Scribner Award for outstanding research in learning and instruction, the David Jonassen Award for excellence in research in the field of instructional design and technology, the James McKeen Cattell Award for a lifetime of outstanding contributions to applied psychological research, and the American Psychological Association's Distinguished Contribution of Applications of Psychology to Education and Training Award. He was ranked #1 as the most productive educational psychologist in the world in *Contemporary Educational Psychology* and #1 as the most cited educational psychologist in Google Scholar. He has served as Principal Investigator or co-Principal Investigator on more than 40 grants, including recent grants from the Office of Naval Research, the Institute of Education Sciences, and the National Science Foundation. He is former editor of the *Educational Psychologist* and former co-editor of *Instructional Science*, and he serves on the editorial boards of 12 journals mainly in educational psychology. He is the author of more than 500 publications including 30 books, such as *e-Learning and the Science of Instruction: Fourth Edition* (with R. Clark), *The Cambridge Handbook of Multimedia Learning: Second Edition* (editor), *Computer Games for Learning*, *Applying the Science of Learning*, *Learning as a Generative Activity*, *How to Be a Successful Student*, *Learning and Instruction: Second Edition*, *Handbook of Research on Learning and Instruction: Second Edition* (co-editor with P. Alexander), and *Handbook of Game-Based Learning* (co-editor with J. Plass and B. Homer).

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