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Managing Cognitive Load in Adaptive Multimedia Learning

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DEDICATION

To most important women in my life:
my wife Marika,
my daughter Maria,
my mother Olga,
my sister Larisa.

Foreword: The Next Phase in Multimedia Learning

Multimedia learning refers to learning from words and pictures. The words can be spoken or printed and the pictures can be illustrations, photos, animation, or video. Examples of multimedia learning include paper-based environments such as text and illustrations, computer-based environments such as animation and narration, and live environments such as a narrated PowerPoint presentation. If you want to create effective learning environments for students or effective training environments for trainees, you need to understand how to use words and pictures to promote learning.

As summarized in the table, there have been three major phases in research on multimedia learning. First, in work dating back to the 1980s and earlier, the major focus was on determining whether adding pictures to text would improve student learning. Research on this topic included studies of the role of illustrations in text, placing graphic advance organizers before lessons, and using scientific visualizations to help explain scientific concepts. As showcased in *Multimedia Learning* (Mayer, 2001), my colleagues and I have found strong and consistent evidence for what I call the *multimedia effect*: People learn better from words and pictures than from words alone. Thus, the first major accomplishment of research on multimedia learning was the creation of a research base supporting the multimedia effect. You can think of this phase as Multimedia Learning 1.0, in which the main goal has been to test for whether there is a multimedia effect.

Phase	Focus	Initial Period	Research Question	Example
Multimedia Learning 1.0	Search for an effect	Pre-1990s	Do pictures help?	Multimedia effect
Multimedia Learning 2.0	Search for design principles	1990s	Which features of multimedia help?	Spatial contiguity principle
Multimedia Learning 3.0	Search for boundary conditions	2000s	Under what conditions do features of multimedia help?	Expertise reversal effect

Early work culminating in persistent evidence for the multimedia effect was encouraging because it suggested that instructional designers could improve student learning by incorporating graphics into their lessons. However, it was clear that all forms of multimedia instructional messages were not equally effective, so the next step in multimedia learning research was to determine which features of multimedia instructional messages improved student learning. As shown in the second line of the table, in work largely underway in the 1990s, the major focus was broadened to include research on determining the features of effective multimedia. This work lead to the creation of principles for multimedia design, many of which are highlighted in *The Cambridge Handbook of Multimedia Learning* (Mayer, 2005). Exemplary principles include the *spatial contiguity principle* (People learn better when printed words are placed near rather than far from corresponding pictures on the screen or page), *coherence principle* (People learn when better when extraneous material is excluded rather than included), *modality principle* (People learn better when words are spoken rather than printed), and *personalization principle* (People learn better when words are in conversational style rather than formal style). You can think of this phase as Multimedia Learning 2.0, in which the main goal has been to test research-based principles of multimedia design.

We are now entering a third phase in research on multimedia learning in which the goal is to identify the boundary conditions under which the multimedia design principles apply. As shown in the third line of the table, in work largely underway in the 2000s, the focus has broadened once again to include research on determining when and for whom the principles apply. An important example of this phase is reflected in the *expertise reversal effect* (Kalyuga, 2005)—the finding that multimedia design principles that improve learning for low-experience learners may be ineffective or even harmful for high-experience learners. For example, an important boundary condition for the spatial contiguity principle is that the effect of spatial contiguity is strong for learners with low domain knowledge but not for learners with high domain knowledge (Mayer, 2001). Importantly, the boundary conditions can be used to test—and if necessary modify—theories of multimedia learning. You can think of this phase as Multimedia Learning 3.0, in which the main goal has been to establish the boundary conditions for multimedia design principles.

The book you are reading represents an important product of this emerging third phase of research on multimedia learning. In particular, Slava Kalyuga expands the field of multimedia learning by focusing on the role of learner's prior knowledge. He shows how learning is improved when multimedia principles are adapted to the knowledge level of the learner. His thesis is that instructional designers need to know what the learner knows (through embedded assessments) and to modify the lesson accordingly (through adaptation of instruction). In short, different instructional methods should be used for low-knowledge learners and high-knowledge learners, or as an individual learner progresses from low- to high-knowledge in a domain. The challenge facing instructional designers is how to encourage learners to engage in productive cognitive processing during learning without creating cognitive overload. Slava Kalyuga shows how this goal can be achieved by being sensitive to the knowledge level of learners.

In short, the book you are holding is a prime example of Multimedia Learning 3.0—the newest phase in multimedia learning research. A commendable hallmark of the book is that the author takes an *evidence-based approach*—by basing the book on scientific research findings, and a *theory-based approach*—by basing the book on research-tested theories of how people learn from words and pictures. If you are interested in the latest trends in multimedia learning, then *Managing Cognitive Load in Adaptive Multimedia Learning* belongs on your bookshelf.

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Prof. Richard E. Mayer is professor of psychology at the University of California, Santa Barbara (UCSB) where he has served since 1975. He received a PhD in psychology from the University of Michigan in 1973. His research interests are in educational and cognitive psychology, with a current focus on multimedia learning and computer-supported learning. He is past-president of the Division of Educational Psychology of the American Psychological Association, former editor of the Educational Psychologist and former co-editor of Instructional Science, former chair of the UCSB Department of Psychology, and the year 2000 recipient of the E. L. Thorndike Award for career achievement in educational psychology. He was ranked number one as the most productive educational psychologist for the latest 10-year period in contemporary educational psychology. He is the author of 18 books and more than 250 articles and chapters, including Multimedia Learning (2001), The Cambridge Handbook of Multimedia Learning (editor, 2005), Learning and Instruction (2nd ed.) (2008), and E-Learning and the Science of Instruction (2nd ed.) (with R.Clark, 2008). (http://www.psych.ucsb.edu/people/faculty/mayer/index.php)

Preface

Since learning is mostly the work of mind, it is obvious that the design of effective multimedia learning environments should take into account how the human mind works and what are its cognitive limitations. Mental resources we rely on when learning and performing different tasks are very scarce due to limited capacity and duration of working memory, a major component of our cognitive system. Working memory becomes overloaded if more than a few chunks of information are processed simultaneously. Processing and short-term storage demands on working memory cause cognitive load. If this load exceeds working memory limits, the learning will inevitably suffer.

Another essential component of our cognitive architecture is long-term memory that does not have any set limitations both in capacity and duration. Domain-specific knowledge base in long-term memory and associated expertise considerably influence the operation of working memory. The learner prior knowledge is considered as a major means of reducing cognitive load and guiding high-level cognitive activities. Long-term memory knowledge structures and associated cognitive characteristics may significantly change the effectiveness of various multimedia presentations and instructional methods. Therefore, in order to be efficient, instructional presentation formats and methods need to be tailored to cognitive characteristics of individual learners.

This book describes theory- and research-based cognitive principles and design guidelines for managing cognitive load by adapting multimedia learning formats and instructional procedures to levels of learner task-specific expertise. The suggested approaches and techniques are based on contemporary knowledge of human cognitive architecture, cognitive load theory, cognitive theory of expertise, and, most importantly, on extensive empirical studies in controlled experimental conditions. The book strictly follows the evidence-based approach to its recommendations on how to handle cognitive load in multimedia learning.

The book has both a theoretical and practical orientations. It is aimed at those who have academic interests in research on multimedia learning and those with practical interests in designing or selecting effective multimedia learning environments. The intended audience includes academics, educational researchers in multimedia learning, educational technologists, designers of multimedia instruction and assessment systems, and educators. The book could also be used in university graduate and postgraduate courses in instructional psychology and ICT in education, multimedia learning and instructional design, educational technology, and cognition and instruction.

THE CHALLENGES

Although benefits of individualized information presentation formats and instructional procedures have been recognized for long time, most multimedia materials are designed in a fixed, static way. Often, by default, novice users or learners are assumed (implicitly, if not explicitly) as intended audience. However, recent studies of the expertise reversal effect (see Kalyuga, 2005; 2006; 2007 for recent overviews) have indicated that designs and techniques that are effective with novices can lose their effectiveness and even have negative consequences when used with more experienced users. The major multimedia design implication of these studies is that information presentation and design techniques need to change as users acquire more expertise in a domain.

In education, the idea of individualized instruction still remains a mainly unrealized dream because of a very complex nature of the problem (multiple learner characteristics, technical, organizational and other aspects). Lack of suitable online diagnostic techniques has also impeded the development of truly adaptive multimedia learning environments. For these reasons, issues of managing cognitive load by adapting instructions to individual learners, although universally recognized as extremely important, has been avoided by most research projects in the field of cognition and instruction. On the other side, developmental projects in the area of adaptive e-learning are focused mostly on technical issues of tailoring instructional content to learner preferences, interests, choices, history of previous on-line behavior etc., and are not based on learner fundamental cognitive characteristics and principles of cognitive psychology.

This book provides a review of the recent research base and design recommendations and partially fills this need. The purpose of this book is to provide theory- and research-based guidance on information presentation techniques for multimedia and e-learning environments that are best suitable for learners with different and changing levels of knowledge in a specific task domain. The term multimedia in this book refers to the information presentations that use both text (on-screen and/or spoken) and images (still and/or animated). The book focuses on principles and methods that have been extensively researched in recent years. It includes a comprehensive review of the relevant literature, discusses practical implications of the proposed principles and their limitations, and provides concrete examples.

Cognitive load theory provides the basic theoretical framework for the book. According to this theory, limited capacity of our working memory in processing unfamiliar information represents the major factor influencing the effectiveness and efficiency of information presentations and instructional materials. It has also been shown that extensive knowledge base in a specific domain reduces working memory limitations by allowing experts to process information more efficiently. In recent years, there have been many studies of interactions between cognitive load and expertise factors in learning. Multimedia design implications of these studies are the main content of this book.

The interactions between levels of learner prior knowledge and effectiveness of different instructional techniques and procedures that constitute the essence of the expertise reversal effect have been intensively investigated within a cognitive load framework since mid-90s. Although the effect was predicted and explained by cognitive load theory, empirical findings associated with the effect correspond well to general studies of Aptitude-Treatment Interactions (ATI) that were actively investigated in 1960-70s (e.g., Cronbach & Snow, 1977). The chapters of this book review many empirical studies of the expertise reversal effect in multimedia learning, their interpretation within the cognitive load framework, implications for the design of learner-tailored instructional systems, and some recent experimental projects that use these findings in realistic adaptive learning environments.

There are several recent books on instructional design in multimedia environments that are based on empirical research and cognitive theories of learning in a larger pool of multimedia design literature that mostly describes the best practice in the field or personal experience of the authors. Richard Mayer's *Multimedia Learning* (Cambridge University Press, 2001) provides a review of studies carried out at the University of California, Santa Barbara for over a decade. There is a chapter (*Individual Differences Principle*) in this book that provides a brief discussion of the role of learners' prior knowledge in effectiveness of multimedia presentations. Ruth Clark's and Richard Mayer's *E-Learning and the Science of Instruction* (Pfeiffer, 2003; the second edition was published in 2007) also includes some comments on differential effectiveness of selected instructional procedures relative to learners' experience. John Sweller's book, *Instructional Design in Technical Areas* (Australian Council for Educational Research Press, 1999) summarizes studies in cognitive load theory-based design principles, however mostly in paper-based instruction. The recently published *Cambridge Handbook of Multimedia Learning* edited by R. Mayer (Cambridge University Press, 2005) is, probably, the most comprehensive overview of the state-of-the-art in the field. It contains a chapter *Prior Knowledge Principle* that deals with expert-novice differences and provides a brief overview of the relevant studies and design recommendations. *Instructing and Testing Advanced Learners: A Cognitive Load Approach* (by S. Kalyuga; Nova Science Publishers, 2006) provides an overview of studies on expert-novice differences in multimedia learning (involving instructions with on-screen and audio text and diagrams), however, it is focused more on rapid assessment procedures and does not reflect the recent studies of more advanced forms of multimedia learning environments such as instructional animations and simulations. Therefore, this book is intended to add a new important adaptive multimedia learning dimension to available publications that offer cognitive theory-based design guidelines.

ORGANIZATION OF THE BOOK

The book is divided into three sections. The first section describes a general theoretical background and the empirical support for the adopted model of human cognitive architecture and cognitive load theory. Procedures for rapid on-line assessment of user expertise and evaluation of cognitive load are reviewed. This section of the book provides a theoretical framework for discussing cognitive load issues in multimedia learning, as well as general evaluation approaches and measurement instruments used in the following parts of the book. The second section of the book describes cognitively efficient evidence-based instructional techniques, procedures, and different forms of multimedia presentations for learners with different levels of task-specific expertise. It includes different multimedia design techniques appropriate for novice and advanced users in audiovisual presentations, interactive learning environments, animations, and instructional simulations. The third section discusses specific adaptive procedures and methods for dynamic online tailoring of multimedia presentations to levels of task-specific expertise and other cognitive characteristics of individual learners in complex adaptive interactive learning environments. Directions for future research in the field are outlined in the conclusion.

The book contains twelve chapters. A brief description of each of the chapters follows.

Chapter I provides an overview of a contemporary model of human cognitive architecture and its implications for performance and learning. Processing limitations of working memory, which becomes overloaded if more than a few chunks of information are processed simultaneously, influences significantly the effectiveness of performance, particularly in complex tasks. The role of learner prior domain-specific knowledge and associated levels of expertise are considered as means of reducing these limitations and guiding high-level knowledge-based cognitive activities. The available knowledge base is considered as the single most important cognitive characteristic that influences learning and cognitive performance. Understanding the key role of long-term memory knowledge base in our cognition is important to successful management of cognitive load in multimedia learning. This chapter provides a theoretical foundation for the analysis and evaluation of various means of managing cognitive load for learners with different levels of expertise described in the following chapters.

Chapter II provides an introduction to cognitive load theory as an instructional theory that considers instructional design implications of human cognitive architecture outlined in the previous chapter. Based on theoretically and empirically established instructional principles (usually referred to as cognitive load effects or multimedia learning principles), the theory makes specific prescriptions for managing cognitive load in learning and instruction. The chapter describes different types and sources of cognitive load (e.g., effective and ineffective load; intrinsic, extraneous, and germane load) that are associated with different instructional implications and cognitive load effects, design methods and techniques for dealing with potential cognitive overload. Cognitive load factors that could potentially influence efficiency of interactive multimedia applications are analyzed (e.g., levels of element interactivity, their spatial and temporal configurations, redundant representations, representational formats used for input parameters, levels of learner prior experience in a task domain). Basic assumptions of cognitive theory of multimedia learning are discussed.

Chapter III describes cognitive processes leading to the expertise reversal effect and its instructional implications, and provides a review of empirical evidence for the effect. Cognitive studies of expertise (reviewed in Chapter I) demonstrated that prior knowledge is the single most important learner characteristic that influences learning processes. Recently, it has been established that learning procedures and techniques that are beneficial for learners with low levels of prior knowledge may become redundant for more knowledgeable learners. This reversal effect is related to aptitude-treatment interactions (interactions between results of different instructional treatments and student aptitudes). Learner level of prior knowledge or expertise is the aptitude of interest in the expertise reversal effect. The effect is related to the cognitive overload of more knowledgeable learners due to processing redundant for these learners instructional components (as compared to information without redundancy). Therefore, instructional outcomes of different multimedia learning formats and procedures are relative to levels of learner task-specific expertise.

Chapter IV describes a cognitive load-based approach to rapid diagnostic assessment of learners' task-specific expertise that has been designed for online application in adaptive learning environments. Main implication of the expertise reversal effect is the need to tailor instructional techniques and procedures to changing levels of learner expertise in a domain. The availability and levels of acquisition of domain-specific knowledge structures represent the most important factor and critical parameter for adapting multimedia formats to individual learners. In order to design adaptive procedures capable of tailoring instruction in real-time, it is necessary to have online measures of learner expertise. Such measures should be rapid enough to be used in real time. At the same time, they need to have a sufficient diagnostic power to detect different levels of expertise. One of the reasons for low practical applications of the results of aptitude-treatment interaction studies were inadequate aptitude measures. Most of the assessment methods used in those studies were psychometric instruments designed for selection purposes (e.g., large batteries of aptitude tests based on artificially simplified tasks administered mostly in laboratory conditions). Another suggested reason was inability to apply such measures dynamically, in real time, as learners proceeded through a learning session. The idea of the rapid diagnostic approach and results of its initial application in several relatively well-defined task domains are presented in this chapter (with some directions of future research of this approach also indicated). Two possible ways of implementing the approach are described: the first-step method and the rapid verification method. They are based on evaluating knowledge structures that learners are able to activate rapidly and apply to a briefly presented problem situation, thus avoiding cognitive overload associated with alternative search-based solution methods.

Chapter V reviews some techniques that could be used for evaluating cognitive load. Availability of valid and usable measures of cognitive load is essential for providing support for cognitive load-related explanations of the effects predicted and described in cognitive load theory and for general evaluation of learning conditions. Besides, the evaluation of cognitive load provides another indicator of levels of learner expertise in addition to performance scores. As mentioned before, due to available schematic knowledge base, more knowledgeable learners are expected to perform their tasks with lower mental effort than novices. Even though simple subjective rating scales remain the most used measures of cognitive load imposed by instructional materials, new more sophisticated techniques are being developed, especially in multimodal environments associated with performance of complex cognitive tasks. The recent application of concurrent verbal reporting method for evaluating sources of potential cognitive overload associated with multimedia learning is described. This chapter reviews some traditional, as well as novel methods for measuring cognitive load, and approaches to using these measures for estimating instructional efficiency of learning conditions. Different possible ways of combining measures of performance and cognitive load into an integrated indicator of cognitive efficiency are discussed.

Chapter VI describes specific evidence-based methods for managing cognitive load in verbal and pictorial information representations. According to the forms of memory storage representations, there are verbal and pictorial representational modes, whereas according to forms of sensory input, there are auditory and visual information modalities. The chapter considers sources of cognitive load in different modes and modalities of multimedia information presentations. When learners process text and visuals that could not be understood in isolation, the process of integration of verbal and pictorial representations is required. When text and pictures are not appropriately located or synchronized in time, integrating these referring representations may increase working memory load and inhibit learning. Instructional design techniques dealing with such split attention situations may enhance learning. Reducing split-attention in on-screen text and graphics was one of the first and most commonly mentioned application of cognitive load theory. Using dual-mode presentations is considered as an alternative approach to dealing with split attention situations. The chapter discusses means for eliminating redundant components of presentations, coordinating verbal and pictorial information in space and time, segmenting presentations and other techniques, as well as interactions between instructional efficiency of different formats of multimedia presentations and levels of learner expertise in specific task domains.

Chapter VII analyzes different types of interactive learning environments according to levels of involved interactivity and levels of allowed learner control. Interactivity is an important feature of online environments. Sophisticated multimedia learning environments include various forms of interactivity and respond dynamically to learner specific actions. Such environments are active, learner-engaged forms of learning that are expected to promote deep cognitive processes and result in active construction and acquisition of new knowledge. Hypermedia learning environments represent an important online form of interactive multimedia that involve multiple representations, linked information network, and high levels of learner control (content control, sequencing of information, and the control of representational formats). General cognitively-based design guidelines for such environments could be derived from cognitive theories of multimedia learning and cognitive load theory. High levels of cognitive load in interactive learning environments could be caused by the large number of variables involved in corresponding cognitive processes; uncertainty and non-linear relationships between these variables; and temporary delays. In many situations, individual learners carry the burden of deciding when to use additional learning support (if available) and what forms of support to request. While more advanced learners could handle such burden, it may be beyond cognitive resources available to less experienced learners. Different levels of learner prior knowledge are important factor influencing the effectiveness of learning in interactive environments. Cognitive load framework can provide a suitable conceptualization for the general analysis of the conditions and methods for enhancing instructional efficiency of interactive multimedia learning environments. The cognitive aspects of learning in such environments are the main focus of this chapter. General issues in managing cognitive load in interactive learning are discussed, and some specific methods and techniques are suggested for reducing wasteful forms of cognitive load caused by interactive multimedia.

Chapter VIII considers cognitive load aspects of instructional efficiency of dynamic multimedia representations such as animations. According to cognitive theory of multimedia learning, different mental representations are constructed from verbal and pictorial information, and meaningful learning occurs only when the learner actively establishes connections between these representations. The cognitive theory of multimedia learning could also be effectively applied to dynamic visualizations such as animations. Cognitive processes involved in learning from dynamic visual representations are analyzed, and factors influencing cognitive load in animated and static visualizations are considered. The chapter describes the relationship between instructional effectiveness of animated and static visualizations and levels of learner task-specific expertise. According to the expertise reversal effect, continuous animations may be too cognitively demanding for novice learners due to a high degree of transitivity of these visualizations, on the one hand, and limited capacity and duration of working memory, on the other hand. Less knowledgeable learners may benefit more from a set of equivalent static diagrams. However, animations could be relatively more beneficial for more knowledgeable learners who have already acquired a sufficient knowledge base for dealing with issues of transitivity and limited working memory capacity. Optimal forms of tailoring visual dynamic representations to levels of learner expertise are suggested such as setting an appropriate level of visual dynamics and selectively using animations and static visualizations.

Chapter IX analyzes cognitive load issues in online instructional simulations and games. Practical use of software products and physical equipment usually does not lead to understanding of theoretical principles they try to convey because of high cognitive demands of familiarization with equipment and procedures, taking measurements, interpreting data, etc. Limited (if any) cognitive resources remain available for generalizations required for understanding the theory. Simulations may help to partially avoid these problems because they may eliminate the need for handling apparatus and simultaneously represent observable and theoretically predicted variables. Interactive visualizations of abstract knowledge are important benefits of simulations. Simulations may provide environments for exploring hypotheses and receiving immediate feedback, thus enhancing the development of critical thinking and problem-solving skills. However, high levels of working memory load could be responsible for instructional failures of many simulations. Many instructional simulations and games represent purely exploratory learning environments with limited guidance for learners. From cognitive load perspective, random search procedures that novice learners have to use in such environments may impose excessive levels of working memory load thus interfering with meaningful learning. Optimizing levels of instructional guidance represents the most important means of managing cognitive load and enhancing learning outcomes in such environments. The Chapter describes representational formats (symbolic and iconic representations) for input parameters and levels of instructional guidance as important factors that may differentially influence effectiveness of simulations for learners with various levels of prior knowledge. Concurrent verbal reports for evaluating sources of potential cognitive overload and other empirical data from studies of simulations in high-school science are used to support the theoretical model.

Chapter X provides an overview of theoretical frameworks and empirical evidence for the design of complex adaptive multimedia environments that are tailored to levels of user expertise and other relevant individual cognitive characteristics to optimize cognitive resources available for learning. A major instructional implication of the expertise reversal effect is the need to tailor dynamically instructional techniques, procedures, levels of instructional guidance to current levels of learner expertise. In multimedia online instructional systems, the levels of task-specific expertise may change noticeably as learners develop more experience in a specific task domain. Therefore, the tailoring process needs to be dynamic, i.e. to consider learner levels of expertise in real time as they gradually change during the learning sessions. Personalized adaptive multimedia environments provide individual learners or learner groups with experience that is specifically tailored to them. To achieve effective personalization, various information about the learner is required. Tailoring multimedia environments to individual learner cognitive characteristics is becoming a major means in achieving a true learner-centered experience for learners through their interaction with multiple content sources and presentation formats. The chapter suggests adaptive methodology that is based on previously described empirically established interactions between levels of learner expertise and formats of multimedia presentations (the expertise reversal effect), and on real-time monitoring of users' expertise using rapid cognitive diagnostic methods.

Chapter XI describes evidence-based methods for selecting appropriate levels of instructional support and tailoring instructional guidance to gradually changing levels of learner proficiency in a domain to optimize cognitive load. Within a cognitive load framework, providing optimal levels of instructional support is considered to be the main means of managing cognitive load in adaptive learning environments. Recent studies in expertise reversal indicate that instructional design principles that benefit low-knowledge users may disadvantage more experienced ones. This reversal in the relative effectiveness of different instructional methods is due to increase in cognitive load required for integration of presented supporting information with available knowledge base. The suggested procedures for adapting levels of instructional guidance have been developed in conjunction with empirically established interactions between levels of learner proficiency and instructional techniques. The chapter starts with the description of the processes and approaches to learning complex cognitive skills. The appropriate design models for learning complex skills are presented and different ways of varying levels of learner control in such models are reviewed. The relations between levels of learner expertise and optimal levels of instructional guidance are discussed and specific empirical studies of the expertise reversal for instructional guidance and sequencing of learning tasks are reviewed. The completion tasks and faded worked examples are specific instructional procedures used in the described studies for managing levels of instructional guidance in adaptive learning environments. Real-time monitoring of learner levels of expertise using rapid cognitive diagnostic methods has been used in some of those studies.

Chapter XII suggests different ways of constructing adaptive procedures for efficient cognitively-optimized learning in multimedia environments. The chapter describes adaptive procedures based on rapid diagnostic methods for evaluating ongoing levels of learner task specific expertise. Two specific approaches to the design of adaptive instruction are considered: adaptive procedures based on rapid measures of performance and adaptive procedures based on combined measures of performance and cognitive load (efficiency measures). Higher levels of expertise in a task domain are characterized not only by rapid and effective performance due to a well-organized knowledge base, but also by relatively effortless performance that does not require much cognitive resources and associated cognitive load. Using integrated indicators of cognitive efficiency based on multiple cognitive measures provides alternative adaptive procedures to those based only on performance indicators. The rapid diagnostic approach was successfully used for real-time evaluation of learner levels of expertise in adaptive online tutorials in the domains of linear algebra equations and vector addition motion problems in kinematics. Both first step diagnostic method and rapid verification technique were applied in corresponding adaptive procedures. According to the rapid assessment-based tailoring approach, the tutorials provided dynamic selection of levels of instructional guidance that were optimal for learners with different levels of expertise based on real-time online measures of these levels. In learner-adapted groups, at the beginning of training sessions, each student was provided with an appropriate level of instructional guidance according to the outcome of the initial rapid pretest. Then during the session, depending on the outcomes of the ongoing rapid tests, the learner was allowed to proceed to the next learning stage or was required to repeat the same stage and then take the rapid test again. At each subsequent stage, a lower level of guidance was provided to learner, and a higher level of the rapid diagnostic tasks was used at the end of the stage. The chapter also considers means of optimizing levels of learner control in adaptive task selection procedures.

The book concludes with the note that task-specific expertise is a stage in achieving higher levels of professional expertise that are associated with adaptive