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Developing Effective and Efficient Instructional Environments Based on Cognitive Theory

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Developing Effective and Efficient Instructional Environments

When it comes to the design of learning environments, The National Research Council (2000) frames the discussion this way, "learning theory does not provide a simple recipe for designing effective learning environments; similarly, physics constrains but does not dictate how to build a bridge" (p131). Humans have been studying and improving upon theories of learning dating all the way back to ancient human civilizations. Some of the earliest recorded attempts at producing learning theories are that of the Greek rhetors (Greek term for orator) who used memorization techniques like mnemonics to help them remember their speeches which, at that time, could not be easily written down. From this desire to better understand and increase one's ability to learn, numerous learning theories and instructional methods have been developed.

Thanks to Pavlov's dogs and researchers like Thorndike and B.F. Skinner, behaviorism dominated much of the twentieth century but, with advances in cognitive psychology and neuroscience, a new learning theory, cognitive load theory (CLT), has come onto the landscape and could plausibly dominate the twenty-first century. Two, more specialized, theories of CLT, the cognitive theory of multimedia learning (CTML) and the cognitive-affective theory of learning with media (CATLM) examine multimedia and its effects on the learning process by applying and extending the principles of CLT. Historically, in the development of instructional technology, "multimedia has been developed on the basis of its technological capacity, and rarely is it used according to research based principles" (Moreno & Mayer, 1999). Examples of poorly designed instruction using multimedia are numerous. Too many instructional designers are not trained how to properly use multimedia in instruction or are not knowledgeable in the area of cognitive load theory, or both. To be an effective instructional designer (ID), one must be aware of the research, the learning theories, and the learning principles concerning the effect instruction have on a learner's cognitive load and the derivative instructional design models that have been developed to help implement effective and efficient instructional environments. They must also understand that learners entering into a learning environment are extremely diverse in their existing knowledge base. In order for the appropriate instruction to be applied to each individual learner, a learner's existing knowledge base must be identified in order to avoid applying instruction which might cause cognitive load problems and thereby reduce the effectiveness of the instruction. Taking into account research in the areas of CLT, CTML, CATML and their accompanying principles is an important part of being a successful modern-day instructional designer. Both the nature and the skills needed for currently available jobs are rapidly changing while the information relevant to carrying out those jobs quickly becomes obsolete. This poses higher demands on the workforce with employers stressing the importance of problem solving, reasoning, and creativity to ensure that employees can and will flexibly adjust to rapid changes in their environment (van Merriënboer & Kirschner, 2007, p. 4). Now more than ever, instructional designers need to be able to optimize their instructional designs in order to create successful students who can meet the demands of industry needs. This means being cognizant of all the variables that can result in either a positive or negative impact on a learner's cognitive load in order to produce effective and efficient learning environments. An analysis of published research articles on the positive and negative effects of instruction on cognitive load and how best to determine a learner's existing knowledge base regarding a particular subject matter is the focus of this literature review.

Knowledge and Learning

In order for an instructional designer to fully understand all of the principles involved in making good decisions about instructional design, they must start with a good foundation. In order to develop this foundation we will begin with the concepts of *knowledge* and *learning*. Knowledge is defined by the *Oxford English Dictionary* as (1) facts, information, and skills acquired by a person through experience or education; the theoretical or practical understanding of a subject (Definition of Knowledge, 2010). In order to acquire knowledge one must utilize complex cognitive processes including: perception, learning, communication, association and reasoning (Knowledge, 2010). The knowledge acquisition method that instructional design has control over is learning which we have just learned is a "complex cognitive process." This would seem to imply that cognition then plays a large part in learning in order to gain knowledge.

Cognitive Learning Theories

Behaviorism, a long-standing standard in learning theories and cognitive learning theories are similar in that they both believe that the environment influences learning. Where the two differ is that cognitive learning theories are concerned with the internal processes involved in making sense of the environment (Eysenck & Keane, 2010) (Reiser & Dempsey, 2007). Of the cognitive learning theories, the cognitive information processing theory was first on the scene and began its rise to prominence in the 1970s (Reiser & Dempsey, 2007). Since then other cognitive learning theories like semantic networks, schema theory and cognitive load theory (CLT) have been developed and have become more influential in the development of instructional design. There is a lot of commonality among these four cognitive theories, among those that are most important to modern learning environments rich with multimedia are:

perception and attention, encoding of information, memory, comprehension, active learning, motivation, locus of control, mental models, metacognition, transfer of learning, and individual differences (Alessi & Trollip, 2001).

Perception and Attention

Perception and attention are shaped by three principles: 1) information, whether it's received in visual or aural form, it needs to be received as simply as possible, 2) the method by which information is arranged, spatially and/or temporally, affects student's attention to and perception of it, 3) varying the way information is presented helps to maintain a student's attention.

Encoding

Although humans posses five senses, for the most part instructional input is received via site and sound. Cognitive psychologists believe that the incoming stimuli must be transformed into a format that can be stored in the brain; this process is called encoding. Studies on how students encode information have shown that simultaneously receiving the right types of information visually and audibly can actually improve learning (Clark & Paivio, 1991; Mayer R. , 1997). We'll discuss the dual coding theory and the multimedia principle later in this paper.

Memory

Learning does absolutely no good if what a student learns cannot be recalled when needed. Alessi & Trollip state that there are two principles that underlie almost all memory enhancing methods: principle of organization and the principle of repetition (2001). The principle of organization states that things are remembered better if they are organized. This is why advance organizers are a good instructional tool; they both organize the material prior to learning and call attention to the organizational structure of the information. Mnemonics is also a form of organizing information to enhance retrieval. You've probably heard the principle of repetition all of your life, "practice makes perfect," actually the truth of the matter is that only *perfect* practice makes for perfect performance and studies have shown that practice does logarithmically improve performance (van Merriënboer & Kirschner, 2007).

Comprehension

A big part of cognitive theories is how to build and modify schemas in long term memory; this is where comprehension comes in. Comprehending a concept, a skill or an attitude means that we are able to classify it, apply it, evaluate it, discuss it, manipulate it, and teach it to other people. This is why teachers who have been teaching a subject for awhile have a deeper insight about it – teaching information to others is one of the best ways to learn a subject in-depth.

Active Learning

Active learning means to learn by doing. Good instructional design will include student interactions that are frequent, relevant, interesting, and apply just the right amount of difficulty. This is why it is helpful, when possible, to know the socioeconomic and educational background of the student the instruction is being designed for. Pre-testing can be very helpful in selecting the appropriate active learning strategy.

Motivation

Motivation is also a key factor in designing instructional content. Two models are frequently used in multimedia design Malone's motivation theory and Keller's ARCS motivation theory.

Malone's motivation theory.

This theory identifies four factors that are necessary for instruction to be motivational. First, the instructional material must not only be challenging for the students but also individualized and adjusted for the specific learner, varying the difficulty of the material as the learner's performance improves keeps the learner motivated throughout the instruction. Second, Malone suggests that the instruction should pique the learner's sensual curiosity as well as their cognitive curiosity. Sensory curiosity consists of visual and audio variations that are surprising or attract attention. Cognitive curiosity occurs when the information conflicts with the learners existing information, is contradictory, or is in some ways incomplete. These situations encourage the learner to seek new information that resolves the conflict. Third, is control, which refers to a learner's ability to control the instructional environment either by actions and responses, choices that allow the learner to determine the sequencing, and the notion of power that a learner feels from having some type of creation to show as a result of the instruction. Malone's final motivational factor is fantasy. Fantasy is when a student can imagine themselves in environments that are realistic to the subject being learned or even surrealistic such as in games or simulations.

Keller's ARCS motivational theory.

This theory is all in the acronym ARCS: *attention*, *relevance*, *confidence*, and *satisfaction*. We discussed *attention* to some degree earlier, but one point that Keller makes in his theory which is worth noting is that a student's attention must be captured early in the lesson and then maintained throughout. This reinforces the idea that piquing a student's curiosity and varying content throughout the instructional process are good strategies to implement. *Relevance* can prove motivational if the instructor or instructional method can demonstrate to students why the material is important to their lives. Developing a student's *confidence* might be implemented by giving the user more control of the learning environment, offering many attempts at being successful during the learning process, and making the expectations for learning clear to the learner. *Satisfaction* can come from encouragement, a sense of progress, and fairness just to name a few strategies.

Locus of Control

Locus of control is another way of saying give the learner the ability to take control of the learning process by enabling them to control sequencing, pace, content, methodology, or other instructional factors.

Mental Models

A mental model refers to the schemas a learner has built into their long term memory. By recalling these schemas learners can reduce the amount of working memory required to solve problems. Studies which compare novices to experts, as in the famous chess master studies (Chase & Simon, 1973), shows that experts have a considerably more schematic structures from which to draw on for problem solving than novices; schemas that have been developed from years of experience working with a particular subject.

Metacognition

Metacognition refers to a person's ability to be aware of their own cognitive capabilities. Research shows that high achievers have good metacognition in addition to good cognitive abilities. General strategies for increasing a learner's metacognitive skills are self-evaluation, reflection, and practice activities aimed at actually developing metacognitive skills.

Transfer of Learning

Transfer of learning is one of the most studied principles of cognitive learning (Cormier & Hagman, 1987). Transfer of learning is concerned with a learner's ability to take what they learn and apply it to situations similar to that learned during instruction (near transfer) and transfer of the problem solving techniques or psychomotor skills to situations considerably different than the context in which they were learned (far transfer).

Individual Differences

The principle of individual differences centers on the fact that not all people are alike and thereby instruction shouldn't be presented in the same way to each and every person. This is where the development of intelligent tutors can have the most impact in instructional design. By adapting the learning process to a learner's pre-existing knowledge and preferred learning method could have a significant improvement on the learning outcome (Anderson, 2007).

Cognitive Load Theory

Although Mary Driscoll in *Trends and Issues in Instructional Design* (Reiser & Dempsey, 2007), Moreno and Park in *Cognitive Load Theory* (Plass, Moreno, & Brüken, 2010), and Allessi & Trollip in *Multimedia for Learning: Methods and Development* (2001) don't agree precisely on the origins of the cognitive load theory, there does appear to be a consensus among them and other researchers that CLT is currently among the more popular of the cognitive learning theories and is considered one of the most influential theories in instructional design. This is due in part to many recent advances in cognitive neuroscience, like PET scans and fMRIs, which have provided increasing evidence for the validity of many principles of the cognitive load theory (Merriam, Caffarella, & Baumgartner, 2007) (Dual-coding Theory, 2009). The main precepts of cognitive load theory are the following: working memory (aka short-term memory) is limited to holding seven items, plus or minus two (Miller, 1994), if a learner does not possess any schemas (organizational structures) in long-term memory related to the subject being learned then working memory can be quickly overloaded with information, causing a cognitive overload that reduces a person's ability to learn. Essentially, what cognitive load means to instructional designers is that in order for instruction to be both effective and efficient, designers need to be cognizant of these three factors 1) the number of elements being presented and the amount that they interact with each other cannot exceed the amount of available working memory, 2) the instructional presentation should not hamper the learning process by adding to the cognitive load in working memory and 3) the instruction should utilize techniques which afford the learner to effectively produce subject matter schemas in long term memory and rule automaticity. In CLT terminology the previous three factors are referred to as *intrinsic load*, *extraneous load*, and *germane load* respectively.

An effective analysis of an instructional presentation needs to identify ways to reduce extraneous load (Sweller J. , Cognitive load theory, learning difficulty and instructional design, 1994). Instructional designers should make every attempt to reduce its effect on cognitive load by implementing, where necessary, the following principles: the goal-free effect, the worked-example effect, the split-attention effect, the completion effect, and the redundancy effect. The goal-free effect demonstrates why instructional designers should use goal-free problems instead of means-ends analysis in order to focus a student's attention on problem states and available operators (Owen & Sweller, 1985; Sweller, Mawer, & Ward, 1983; Tarmizi & Sweller, 1988). The worked-example effect encourages instructional designers to replace means-ends analysis with worked-examples thereby reducing extraneous cognitive load by focusing a student's attention on problem states and solution steps (Cooper & Sweller, 1987; Sweller & Cooper, 1985). The split-attention effect is cause for replacing the placement of multiple sources of mutually referring information with a single, integrated source of information in order to reduce extraneous cognitive load by avoiding the need to mentally integrate the information sources (Chandler & Sweller, 1991; Chandler & Sweller, 1992; Sweller & Chandler, 1994; Sweller, Chandler, Tierney, & Cooper, 1990). The completion effect encourages instructional designers to design instruction that uses partially completed problems rather than having students' solve entire problems in order to focus attention by reducing the size of the problem space (Paas, 1992; van Merriënboer & de Crook, 1992). The redundancy effect can be eliminated by instructional designers by replacing multiple sources of information that can be understood in isolation with one source of information; in this case extraneous cognitive load is reduced by eliminating the processing of redundant information (Chandler & Sweller, 1991; Sweller & Chandler, 1994).

Considered to be a tougher if not impossible challenge for the instructional designer is the reduction of intrinsic load which deals with the number of elements being presented in the instruction and how much those elements interact with each other. There has been some disagreement as to whether instructional design can affect intrinsic load or not (Sweller J. , 1994; Paas, Renkl, & Sweller, 2003). Recent research however, seems to support the argument that it can (van Merriënboer & Sweller, 2005). Intrinsic load also factors in the learner's prior knowledge of the subject matter and is referred to as the "additivity hypothesis" which states that:

> when people are faced with new material, the cognitive load imposed by the material will consist of the intrinsic cognitive load due to element interactivity and extraneous cognitive load determined the instructional design used. If the total cognitive load is excessive, learning and problem solving will be inhibited (Sweller J. , 1993)

This too is a hypothesis that is still open for debate, the question being whether intrinsic and extraneous loads are indeed reducible (Paas, Renkl, & Sweller, 2003; Paas, Tuovinen, Tabbers, & van Gerven, 2003), but again new research seems to favor of the argument intrinsic load may be altered by reducing element interactivity, although "by artificially reducing intrinsic cognitive load, understanding is also reduced" (van Merriënboer & Sweller, 2005).

Optimally, by reducing extraneous load and controlling intrinsic load, instructional designers can turn their focus to increasing germane load in their instructional materials so that the cognitive resources of working memory can be devoted to schema acquisition and rule automation (Plass, Moreno, & Brüken, 2010). Schema acquisition is the transfer of new information form short term memory to long term memory which either becomes a new schema in long term memory or modifies an existing one. Schema automation (aka rule automation) is the ability to recall a schema from long term memory without having to think about it. Freeing available cognitive capacity by reducing extraneous load will not necessarily result in increased learning unless the freed activities are directed to activities that are relevant for schema acquisition and rule automation. If designed properly germane load can increase a person's ability to learn whereas extraneous load will reduce their ability to learn when intrinsic load is high. There are studies that show that extraneous load has little or no effect when intrinsic load is low.

The Effects of Multimedia on Cognitive Load

Mayer defines multimedia instruction as "presentations involving words and pictures that are intended to foster learning" (2009). When designing instruction one of the most important cognitive load principles to keep in mind is that of dual coding theory (DCT). A theory first brought to light by Clark & Paivio in their 1991 article published in *Educational Psychology Review* which, as Alessi and Trollip put it, "suggests that learning is enhanced when complementary information codes are received simultaneously" (2001). Although there had been some research written about dual coding by Yates (1966) and Rossi as early as the 1960s, the Clark & Paivio article is considered to be the seminal paper on the subject. Mayer and Moreno have used the term *multimedia principle* which is displayed in figure 1. to describe the benefits of combining different visual and aural information. It follows from dual coding theory and applies directly to interactive multimedia (Alessi & Trollip, 2001).

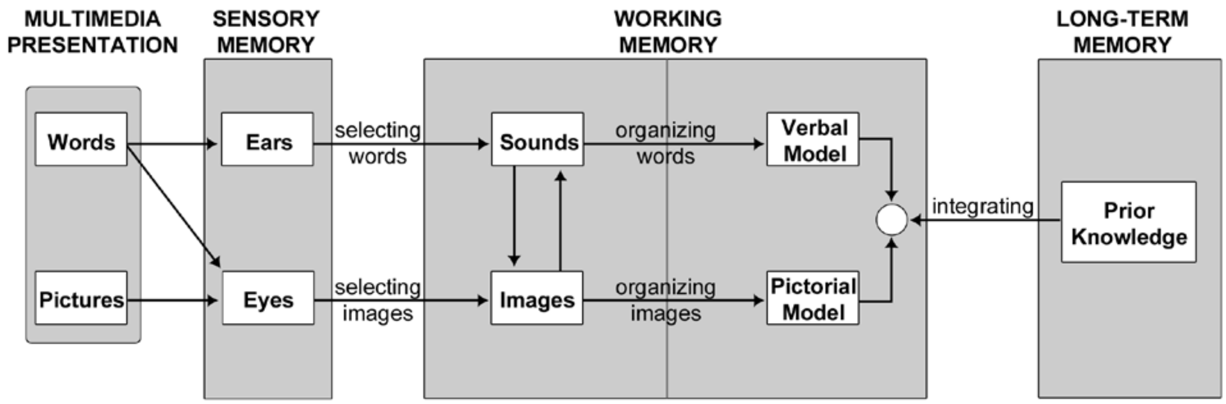

Figure 1. Cognitive theory of multimedia learning. Adapted from figure 7.1 Mayer & Moreno in Cognitive load theory Jan L. Plaas, Roxana Moreno, Roland Brünken (Eds.), 2010

In addition to the multimedia principle, Mayer describes the following eleven empirically tested principles to keep in mind when designing instructional content that utilizes multimedia elements: the *coherence principle*, the *signaling principle*, the *redundancy principle*, the *spatial contiguity principle*, the *temporal contiguity principle*, the *segmenting principle*, the *pre-training principle*, the *modality principle*, the *personalization principle*, the *voice principle*, and the *image principle* (2009). The *coherence principle* states that people learn better when extraneous material is excluded rather than included. According to Mayer in thirteen out of fourteen tests, learners who received concise multimedia presentations performed better on tests of transfer and that the median effect size was .97. This principle agrees with cognitive load theory which also emphasizes the importance of reducing extraneous load in order to help facilitate learning. The *signaling principle* states that people learn better when cues that highlight the organization of the essential material are added, Mayer cites a smaller sampling for this principal five out of six test where the principle showed better transfer, also a smaller media effect size of .52. The *redundancy principle* is the same as CLT's redundancy effect where people experience an extraneous cognitive load when graphics, narration, and printed text was presented simultaneously as opposed to graphics and narration, narration only. The median effect size was .72. The *spatial contiguity principle* is similar to CLT's split-attention effect where students learn better when corresponding words and pictures are presented near, spatially or temporally, rather than far from each other. This principle has a rather high media effect size of 1.09. The *temporal contiguity principal* states that students learn better when corresponding words and pictures are presented simultaneously rather than successively. This principle has the highest median effect size of all of the multimedia principles, 1.31. The *segmenting principle* states that students learn better when multimedia messages are presented in a user-paced format rather than as a continuous unit. The media effect size is .98. The *pre-training principle* states that students learn more deeply from a multimedia message when they know the names and characteristics of the main concepts. This is consistent with CLT claims that intrinsic cognitive load is reduced when learners are able to work from existing schemas. The median effect size is .85. The *modality principle* states that people learn more deeply from pictures and spoken words than from pictures and printed words. This principle is similar to Clark and Paivio's dual coding theory which demonstrated that learners do better when both the visual and auditory perceptions are activated instead of having text and graphics both competing for attention by the learner's visual channel alone. The median effect size was 1.02. The *personalization principle* states that students learn better from multimedia presentations when words are in conversational style rather than formal style and has a comparatively high media effect size of 1.11. The *voice principle* states that students learn better when narration is spoken in a human voice rather than a machine voice. The median effect size is .78. The last of Mayer's principles is the *image principle* which states that people do not necessarily learn better when the speaker's image is added to the screen. In five experiments, the median effect size favoring adding the speaker's image to the screen was only .22.

The 4C/ID Model

Fortunately for instructional designers, a learning model has been developed which takes in account the principles of the cognitive load theory, the four component instructional design model (4C/ID) for complex learning. The 4C/ID model calls for learning tasks to be sequenced in ways that reduce cognitive load (van Merriënboer, Kirschner, & and Kester, 2003). The 4C/ID model focuses on authentic learning tasks based on real-life tasks as the driving force for teaching and learning. The basic idea behind this focus is that such tasks help learners to integrate knowledge, skills and attitudes; stimulate them to coordinate constituent skills; and facilitate transfer of what is learned to new problem situations (Merrill, 2002; van Merriënboer J. , 2007; van Merriënboer & Kirschner, 2001). The 4C/ID model instructional approach is a holistic design approach which can offer a solution for three persistent problems in the field of education: compartmentalization, fragmentation, and the transfer paradox (van Merriënboer & Kirschner, 2007)

Conclusion

Too often it has been the case that instructional designers have been ill-prepared to meet the challenge of properly preparing the modern day workforce to meet the needs of industry. Primarily the problem has been that the instruction is being developed without regard to its actual impact on cognitive load which is stifling learning outcomes. In order to create effective and efficient instructional environments designers need to be cognizant of and apply the principles derived from cognitive theories like the cognitive load theory (CLT), the cognitive theory of multimedia learning (CTML) and the cognitive-affective theory of learning with media (CATLM). The four component instructional design model (4C/ID) embraces these theories in its framework and provides instructional designers a viable methodology to follow for the implementation of instructional environments.

Works Cited

Alessi, S. M., & Trollip, S. R. (2001). *Multimedia for learning: Methods and development.* Boston: Allyn and Bacon.

Anderson, J. (2007). *How can the human mind occur in the physical universe.* New York: Oxford University Press.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction , 8*, 293-332.

Chandler, P., & Sweller, J. (1992). The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psychology , 62*, 233-246.

Chase, W., & Simon, H. (1973). *The mind's eye in chess. In W.G. Chase, ed., Visual information processing.* New York: Academic Press.

Clark, J., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review , 3* (3), 149-210.

Cooper, G., & Sweller, J. (1987). The effects of schema acquisition and rule of automation on methematical problem-solving transfer. *Journal of Educational Psychology , 79*, 347-362.

Cormier, S., & Hagman, J. (1987). *Transfer of learning.* San Diego: Academic Press.

Definition of Knowledge. (2010). Retrieved November 30, 2010, from Oxford Dictionaries: http://oxforddictionaries.com/view/entry/m_en_us1261368#m_en_us1261368

Dual-coding Theory. (2009, December 30). Retrieved March 20, 2010, from Wikipedia: http://en.wikipedia.org/wiki/Dual-coding_theory

Eysenck, M. W., & Keane, M. T. (2010). *Cognitive pschology: A student's handbook.* New York: Psychology Press.

Knowledge. (2010, November 2). Retrieved November 6, 2010, from Wikipedia: http://en.wikipedia.org/w/index.php?oldid=394343866

Mayer, R. E. (2009). *Multimedia learning 2nd Ed.* New York: Cambridge University Press.

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

Merriam, S. B., Caffarella, R., & Baumgartner, L. (2007). *Learning in adulthood.* San Francisco: Jossey-Bass.

Merrill, M. (2002). First principles of instructional design. *Educational Technology Research and Development , 50*, 43-59.

Miller, G. A. (1994). The magical number seven, plus or minus two: Some limits in our capacity for processing information. *Psychological Review , 101* (2), 343-352.

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology , 91* (2), 358-368.

National Research Council. (2000). *How people learn: Brain, mind, experience, and school.* Washington, D.C.: National Academy Press.

Owen, E., & Sweller, J. (1985). What do students learn while solving mathematics problems? *Journal of Educational Psychology , 77*, 272-284.

Paas, F. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive load approach. *Journal of Educational Psychology , 84*, 429-434.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive Load Theory and instructional design: Recent developments. *Educational Psychologist , 38*, 1-4.

Paas, F., Tuovinen, J., Tabbers, H., & van Gerven, P. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist , 38*, 63-71.

Plass, J. L., Moreno, R., & Brüken, R.. (2010). *Cognitve load theory.* New York: Cambridge University Press.

Reiser, R. A., & Dempsey, J. V. (2007). *Trends and issues in instructional design and technology.* Upper Saddle River, NJ: Pearson-Merrill/Prentice Hall.

Sweller, J. (1994). Cognitive load theory, learning difficulty and instructional design. *Learning and Instruction , 4*, 295-312.

Sweller, J. (1993). Some cognitive processes and their consequences for the organisation and presentation of information. *Australian Journal of Educational Psychology , 45*, 1-8.

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition and Instruction , 12* (3), 185-233.

Sweller, J., & Cooper, G. (1985). The use of worked examples as a substitute for problem solving in learning algebra. *Cognition and Instruction , 2* (1), 59-89.

Sweller, J., Chandler, P., Tierney, P., & Cooper, M. (1990). Cognitive load as a factor in the structuring of technical material. *Journal of Experimental Psychology: General , 119*, 176-192.

Sweller, J., Mawer, R., & Ward, M. (1983). Development of expertise in mathematical problem solving. *Journal of Experimental Psychology , 112* (4), 639-661.

Tarmizi, R., & Sweller, J. (1988). Guidance during methematical problem solving. *Journal of Educational Psychology , 80*, 424-436.

van Merriënboer, J. (2007). *Alternate models of instructional design: Holistic design approaches and complexe learning.* Old Tappan, NJ: Merrill/Prentice Hall.

van Merriënboer, J., & de Crook, M. (1992). Strategies for computer-based programming instruction: Program completion vs. program generation. *Journal of Educational Computing Research , 8* (3), 365-394.

van Merriënboer, J., & Kirschner, P. (2007). *Ten Steps to Complex Learning: A systematic approach to four-component instructional design.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

van Merriënboer, J., & Kirschner, P. (2001). Three worlds of instructional design: State of the art and future directions. *Instructional Science , 29*, 429-441.

van Merriënboer, J., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review , 17*, 147-177.

van Merriënboer, J., Kirschner, P., & and Kester, L. (2003). Taking the load off a learner's mind: Instructional design for complex learning. *Educational Psychologist , 38* (1), 5-13.