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Designing Multimedia for Meaningful Online Teaching and Learning

Krista P. Terry
Radford University

Peter E. Doolittle
Virginia Polytechnic Institute and State University

Stephanie B. Scheer
University of Virginia

Andrea McNeill
Virginia Polytechnic Institute and State University

The development of distance and distributed learning environments on college campuses has created a need to reconsider traditional approaches to teaching and learning by integrating research and theories in human learning, pedagogy, and instructional technology. Creating effective and efficient multimedia for Web-based instruction requires a working knowledge of human memory constructs, including working memory, dual coding, and cognitive load. The authors synthesize research on human memory, cognition, and learning in order to provide multimedia practitioners with a set of basic principles for designing multimedia for meaningful Web-based teaching and learning.

As colleges and universities strive to integrate technology into online teaching and learning environments, the need arises for educators to investigate how current research in human learning, pedagogy, and instructional technology can foster more effective instruction. In the recent past, however, Anderson, Reder, and Simon (1998) have lamented that the "science of human learning has never had a large influence on the practice of education" (p. 227). Although this is unfortunate, the new emphasis on developing and utilizing innovative technologies as learning tools has fostered renewed interest in human learning and pedagogical research.

This interest in the integration of human learning and pedagogy within online instructional environments has resulted in a change in perspective: "There is a subtle shift of attention from what *can* be done with the technology to what *should* be done in order to design meaningful instructional applications" (Rouet, Levonen, & Biardeau, 2001, p. 1). Specifically, multimedia and multimedia applications have moved beyond a technology-driven focus to a focus on the relationships between human learning, pedagogy, and technology.

This article endeavors to explore these relationships. We examine the relevance of theoretical constructs of human memory such as working memory, dual coding, and cognitive load to multimedia design attributes in order to create effective and efficient online pedagogy. In the process of investigating these relationships, we develop and apply a set of online multimedia pedagogical principles.

Working Memory, Dual Coding, and Cognitive Load

Creating effective and efficient multimedia for online instruction requires a working knowledge of human memory constructs. Specifically, multimedia that is compatible with these memory constructs result in more effective and efficient learning, retention, and transfer (see Clark and Mayer, 2003; Mayer, 2001). The challenge is to delineate and operationalize which of the memory constructs to attend to when doing multimedia design for online instruction:

> The challenge in [multimedia design] is to build lessons in ways that are compatible with human learning processes. To be effective, instructional methods must support these processes. That is, they must foster the psychological events necessary for learning. (Clark & Mayer, 2003, p. 30)

The following sections delineate the essential tenets of three key human learning processes: working memory, dual coding, and cognitive load. These tenets will then be applied to the design of multimedia for the purpose of creating effective and efficient online instruction.

Working Memory Theory

Working memory is that aspect of human memory that is active at the interface between human thought and experience. For example, imagine a student using the Google Internet search engine from its main search page (http://www.google.com). The student would be thinking about what he or she wanted to retrieve from the search engine and then creating in his or her mind a relevant search term or phrase using a mental search strategy. The student would then type this term or phrase into the search text box and press the *Enter* key or click on the Google *Search* button. Thinking about search strategies, terms, or phrases and how to use the search engine all would occur within working memory. Ultimately, working memory represents a constellation of interrelated cognitive processes responsible for recognition, comprehension, reasoning, problem solving, and decision making (Miyake & Shah, 1999).

Perhaps the most salient principle of working memory is that it represents a limited resource (Baddeley, 1986; Miller, 1956). Specifically, working memory can process only a small amount of information at any given time. For example, imagine a novice search engine user attempting to use the Google *Advanced Search* page (http://www.google.com/advanced_search/). Unlike the basic Google search page, which has very few options, the Advanced Search page has many options to consider and involves much more jargon-laden text that needs to be deciphered (for instance, file format, domain, SafeSearch). The Advanced Search page allows users to do more than enter simple search terms or phrases. Users can also limit searches, format the search output, search specific domains or topics, and search only specific pages. For a novice, the large number of words to be read, features to comprehend, decisions to be made, strategies to employ, and behaviors to engage in are likely to require more resources than his or her working memory can accommodate. This overtaxing of working memory's resources will result in poorer performance. Ultimately, the limits on working memory—that is, how much can be processed at any given time—are somewhat vague and less important than the general tenet that working memory represents a limited resource.

Dual Coding Theory

Dual coding theory complements and builds on the concept of working memory and posits that the mind utilizes two main information-processing systems: verbal and nonverbal (Paivio, 1971, 1990). The verbal system represents and processes verbal information (for example, words, sentences, stories), while the nonverbal system represents and processes nonverbal information (for example, pictures, music, odors). Each information system, verbal and nonverbal, represents and processes specific types of information regardless of which sensory modality is responsible for experiencing the information (see Table 1). For example, reading a Web page and listening to audio narration are both represented and processed by the verbal system, while seeing an animated rotating cube and holding a cube in one's hand are both represented and processed by the nonverbal system.

A second critical concept of dual coding theory, beyond the existence of verbal and nonverbal information processing systems, is that each system is subject to working memory limitations (Mayer, Heiser, & Lonn, 2001; Sadoski & Paivio, 2001). For example, multimedia instructional materials often contain a picture of an instructor talking (nonverbal), auditory narration of the instructor's comments (verbal), text narration of the instructor's comments (verbal), and PowerPoint slides (verbal). In this case, the individual viewing this multimedia training application is likely to find his or her verbal information processing system overloaded (for an example of this type of instruction, see http://www.impatica.com/movies/impatica/250/OnCueTour/OnCueTour-128.html). Ultimately, dual coding theory focuses on two tenets: The human mind comprises two processing systems, verbal and nonverbal; and each of the two processing systems are constrained by working memory's limited resources.

Cognitive Load Theory

As explained previously, working memory theory provides broad constraints on cognition, while dual coding theory provides a more detailed division of one's cognitive efforts into verbal and nonverbal information processing. These cognitive efforts, however, are further refined and clarified through the construct of *cognitive load theory.* Cognitive load reflects the cognitive and working memory resources required to complete a given task. For example, watching a short video clip about the weather would likely result in very little cognitive load (see, for example, http://www.weather.com/newscenter/topstory/video.html), while engaging in a Java applet focused on physics problem solving, with multiple options, would likely result in significantly greater cognitive load (see, for instance, http://www.astrophysik.unikiel.de/pershome/supas086/launcher/launcher.html).

Table 1
Examples of Verbal/Nonverbal Cognitive Processing Based on Specific Modality Experiences

	Cognitive Processing	
Modality	**Nonverbal**	**Verbal**
Visual	Looking at pictures, animations, or a mirror	Reading a book, a billboard, or the name on a mailbox
Auditory	Listening to music, cars on a highway, or animal sounds	Listening to a speech, a song, or a conversation
Haptic	Touching cashmere, another's arm, or the texture of glass	Reading Braille, finger spelling, or sign language
Gustatory	Tasting food, licking a stamp, or eating berries	N/A
Olfactory	Smelling food, burning wood, or a lighted match	N/A

Additionally, cognitive load theory posits that instructional materials impose three different types of load on working memory: *intrinsic cognitive load, extraneous cognitive load,* and *germane cognitive load* (Gerjets & Scheiter, 2003; Paas, Renkl, & Sweller, 2003). *Intrinsic cognitive load* refers to the essential cognitive and working memory resources necessary to complete a given task. Intrinsic cognitive load is generally considered an innate aspect of a given task that is largely beyond the control of the teacher or student (van Merrienboer, Kirschner, & Kester, 2003). *Extraneous cognitive load* refers to the cognitive and working memory resources necessary to complete a given task beyond that of the essential intrinsic cognitive load. Extraneous cognitive load is typically viewed as resulting from poor instructional design, including poor multimedia design, and is generally considered detrimental to the learning process (van Merrienboer et al., 2003). Finally, *germane cognitive load* is comprised of those cognitive and working memory resources dedicated to engaging in activities that support the learning process beyond the simple completion of the task at hand (Paas et al., 2003).

A multimedia example involving intrinsic, extraneous, and germane cognitive load is *National Geographic's Remembering Pearl Harbor* site (http://plasma.nationalgeographic.com/pearlharbor/ax/map.html).

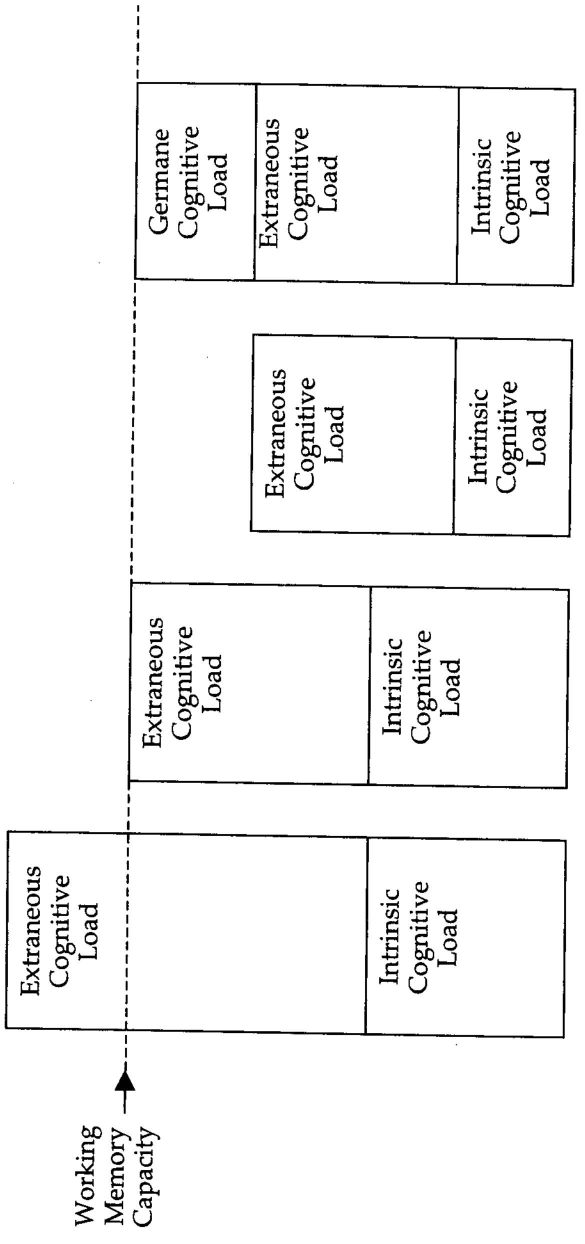
This site uses an interactive, user-controlled module designed to explore the timeline and events involved in the Japanese attack on Pearl Harbor on December 7, 1941. The essential intrinsic cognitive load created when users interact with the Pearl Harbor site includes comprehending the timeline-driven nature of the site, watching relevant animations of the battle, listening to audio narration describing the battle, and synthesizing the animations and narrations. In addition, however, detrimental extraneous cognitive load is generated through the awkwardness of the animated expanding timeline and the presence of so many visuals—specifically, the timeline, the full-sized map, the resizing map, the event summary, and the redundant "full story" link. Finally, if users possess the working memory resources necessary to accommodate the intrinsic and extraneous cognitive loads being placed on them, then perhaps they may begin to engage in tasks that result in germane cognitive load. Specifically, they may begin to work on developing general critical-thinking or problem-solving skills, using the Pearl Harbor site, that are generalizable beyond working with the site itself.

Intrinsic, extraneous, and germane cognitive loads may be summed to obtain a *total cognitive load,* that is, the total cognitive and working memory resources necessary to complete a given task. Investigating this total cognitive load may lead to several interesting scenarios (see Figure 1). In comprehending these scenarios, one must begin by realizing that working memory is a limited resource (see Figure 1a). These differing scenarios will all be examined using the historical murder mystery site *Who Killed William Robinson?* at the University of Vancouver, British Columbia (http://web.uvic.ca/history-robinson/). This site contains a collection of historical artifacts from the 1860s related to the Robinson murder (newspaper reports, court documents, letters), the general context of the time (other murders and crimes of the time), and the location of the murder (maps, descriptions). The site itself is primarily text, although some graphics (pictures, maps) also are included.

In the first scenario depicted in Figure 1, if the sum of the intrinsic and extraneous cognitive loads exceeds one's working memory capacity, then the learning and performance of the given task will be adversely affected (see Figure 1b). In the case of *Who Killed William Robinson?* the task itself, solving the murder mystery, is likely to result in significant intrinsic cognitive load. In addition, the site contains a vast array of historical documents without extensive organizational scaffolds, a situation that may result in significant extraneous cognitive load.

In the second scenario, if the sum of intrinsic and extrinsic cognitive load is equal to or less than users' working memory capacity, then they

Figure 1
Scenarios Depicting the Relationship Between Working Memory Capacity and the Three Components of Cognitive Load (Intrinsic, Extraneous, and Germane Cognitive Load)



should be able to complete the given task successfully (see Figure 1c). Continuing with the *William Robinson* example, the extraneous cognitive load may be reduced by providing students with graphic organizers designed to allow them to better organize the information they obtain from the site. The use of these organizers would likely reduce the extraneous cognitive load to a more manageable level.

While this scenario is acceptable, it does not leave any cognitive resources available for engaging in additional and beneficial processing beyond the mere completion of the task. If, as in the third scenario, users' cognitive load is reduced further, such that the sum of intrinsic and extraneous cognitive load is less than their working memory capacity, then they may engage in additional synergistic processing, resulting in increased overall performance (see Figure 1d). In the case of *William Robinson,* the teacher may reduce the question "Who Killed William Robinson?" to a series of sub-questions, such as "Who was William Robinson?" "How was William Robinson killed?" "Describe Saltspring Island?" and "How was William Robinson's body found?" The use of these sub-questions would reduce students' intrinsic cognitive load, as each task is now smaller, and if the teacher scaffolds students' progress with graphic organizers, the extraneous load would be reduced as well. This reduction in intrinsic and extraneous cognitive loads would allow the teacher to introduce general problem-solving strategies, a germane cognitive load activity (see Figure 1e).

To sum up, the fundamental goals of multimedia online instruction must be to create online environments and tasks that have manageable intrinsic cognitive load, develop online instruction that reduces extraneous cognitive load, and foster online engagement in active processing that facilitates germane cognitive load. To this end, much research and literature has been devoted to the development of a cognitive theory of multimedia (Mayer, 2001). A cognitive theory of multimedia, informed by dual coding theory and cognitive load theory, provides guidance to educators on how to develop instructional materials that engage learners in meaningful learning tasks without overloading working memory capacity.

A Cognitive Theory of Multimedia

Creating multimedia that balances the constraints of human memory (for instance, working memory, dual coding, and cognitive load) with the goals of higher education (for instance, meaningful learning, retention, and transfer) requires a theory of multimedia instruction grounded in the science of human learning. As the definition of multimedia has evolved from the use of multiple media devices to the use of multiple media elements within a single media device, such as a computer system (see Moore, Burton, and Myers, 1996; von Wodtke, 1993), the focus of the design, development, and utilization of multimedia as an instructional tool has shifted away from a technology-centered approach to a more learner-centered approach. This learner-centered approach is based on the current literature and research on the development of multimedia, which emphasizes the need to design learning environments that pay particular attention to human cognition (see Abbey, 2001; Mayer, 2001).

As educators and designers approach the task of developing multimedia instruction from a more learner-centered perspective, the emphasis on cognitive processing as it relates to learning, retention, and transfer becomes increasingly relevant. Within von Wodtke's (1993) definition of multimedia, multiple media elements such as text, sound, graphics, animation, video, imaging, and spatial modeling are combined within a computer-based environment for the purposes of instruction. Unfortunately, a key constraint within this multimedia environment is that only two sensory channels are available: visual and auditory. Fortunately, the multimedia environment fits comfortably within the previously examined theoretical constructs of working memory, dual coding, and cognitive load. Investigating this relationship between multimedia environments and working memory, dual coding, and cognitive load has led Mayer (2001) formally to propose a *cognitive theory of multimedia learning*.

Mayer's (2001) cognitive theory of multimedia learning posits that learners process visual and auditory information in different cognitive channels, that each channel has a limited processing capability, and that learners process this visual and auditory information actively. These assumptions provide guidance for developing instructional multimedia materials that engage both the verbal and nonverbal systems, function within the limited capacity of both of these systems, and foster active processing within them (Mayer, 1997). By active processing, Mayer (1997) means encouraging students to select relevant information from the instructional environment, organize the information into coherent representations, and connect the verbal and visual representations.

Mayer's (2001) three assumptions have resulted in a set of several principles that address multimedia learning from a cognitive perspective. However, a quick clarification is necessary at this point. Mayer's research is based on students' learning, retention, and transfer from short causeand-effect animated tutorials. He has used these short tutorials to test various learner-centered cognitive principles related to student learning, retention, and transfer within multimedia environments. The principles he has derived from this research are not limited to tutorial-based instructional environments, however, but are generalizable beyond these contexts.

In the following section, we delineate several cognitive principles of multimedia and provide examples to extend these principles into non-tutorial based instructional environments.

Multimedia, Principles, and Pedagogy

When developing learner-centered multimedia, whether the context of such development involves tutorials, simulations, problem solving, instructional tools, or computer games, it is critical to base this multimedia development on cognitive principles in order to engage learners in meaningful learning. Richard Mayer, Roxana Moreno, and their colleagues have derived a series of such multimedia cognitive principles from 15 years of empirical research. Their research, which has generated a robust set of seven cognitive and pedagogical principles that can be used to develop learner-centered multimedia, can be synthesized and applied to online teaching and learning.

The following section introduces the seven cognitive principles of multimedia that have emerged from the collective works of Mayer and Moreno. These principles, and the examples provided, are all grounded in the work of Paivio's (1990) *dual-coding theory,* Chandler and Sweller's (1991) *cognitive load theory,* and Baddeley's (1986, 1999) *working memory model.* These seven principles include the multimedia principle, the modality principle, the redundancy principle, the coherence principle, the contiguity principle, the segmentation principle, and the signaling principle (see Table 2).

The Multimedia Principle

The *multimedia principle* states that individuals learn, retain, and transfer information better when the instructional environment involves both words *and* pictures, rather than words or pictures alone. The multimedia principle, therefore, can be explained based on Paivio's (1990) *dual-coding theory,* which posits that when an individual experiences instruction both verbally and visually, he or she constructs verbal and visual representations of the explanations, and subsequently integrates the two representations into a coherent mental model.

Table 2
Seven Principles of Multimedia Instruction Based on Cognitive Research

Principle	*Definition*
Multimedia Principle	Individuals learn, retain, and transfer information better when the instructional environment involves words and pictures, rather than word or pictures alone.
Modality Principle	Individuals learn, retain, and transfer information better when the instructional environment involves auditory narration and animation, rather than on-screen text and animation.
Redundancy Principle	Individuals learn, retain, and transfer information better when the instructional environment involves narration and animation, rather than on-screen text, narration, and animation.
Coherence Principle	Individuals learn, retain, and transfer information better when the instructional environment is free of extraneous words, pictures, or sounds.
Signaling Principle	Individuals learn and transfer information better when the instructional environment involves cues that guide an individual's attention and processing during a multimedia presentation.
Contiguity Principle	Individuals learn, retain, and transfer information better in an instructional environment where words or narration and pictures or animation are presented simultaneously in time and space.
Segmentation Principle	Individuals learn and transfer information better in an instructional environment where individuals experience concurrent narration and animation in short, user-controlled segments, rather than as a longer continuous presentation

In suggesting that using visual and verbal information provides for an enhanced learning experience, the multimedia principle has many pedagogical ramifications. Specifically, multimedia instructional presentations should utilize words or narration and pictures or animations to give users the ability to synthesize information across both memory channels. For example, the *The Vikings: The North Atlantic Saga* presentation within the Smithsonian Institute Web site (http://www.mnh.si.edu/vikings/) utilizes realistic graphic images, animation, and text to depict the journey of the Vikings. The animated introduction and the Web site itself provide users with an integrated multimedia learning experience.

The *History Channel's* Web site (http://www.historychannel.com/broadband/index_popup.jsp) utilizes streaming video to provide rich images in addition to auditory narration. The site is, therefore, a prime example of how combining visual and verbal information can enhance the learning process. While users are viewing authentic video clips that illustrate the content area of choice, they are also able to listen to descriptions that further promote their understanding of the material.

The Modality Principle

The *modality principle,* which is grounded in the working memory model and cognitive load theory, states that individuals learn, retain, and transfer information better when the multimedia learning event involves auditory narration plus animation rather than on-screen text and animation. Providing learners with narration and animation rather than on-screen text and animation lessens the likelihood of cognitive overload, as individuals will need to attend to only one visual representation (animation) and one auditory representation (narration) as opposed to two visual representations (animation and text).

The pedagogical implications of the modality principle are that when developing multimedia for online teaching and learning, one should utilize narration and animation rather than on-screen text and narration. Stanford University's Center for Professional Development provides a series of *Online Seminars* consisting of simple streamed lectures on a variety of topics (http://stanford-online.stanford.edu/murl/cs547/) that combine narration and video. The *National Geographic* site entitled *Into the Amazon* (http://magma.nationalgeographic.com/ngm/0308/sights_n_sounds/media2.html) is a positive example of the modality principle. It aptly integrates visual imagery in the form of animated pictures with auditory narration. Both of these sites rely only on imagery and narration and do not include on-screen text.

The Redundancy Principle

The *redundancy principle* states that individuals learn, retain, and transfer information better when the multimedia instructional environment involves narration and animation only, rather than narration, animation, and on-screen text. This principle more efficiently utilizes the processes of working memory without evoking cognitive overload by providing learners with one visual representation (animation) and one auditory representation (narration), rather than two visual representations (animation and text) and one auditory representation (narration). Eschewing the on-screen text in favor of narration provides a more efficient multimedia learning environment.

The redundancy principle's significant ramifications for pedagogy will be discussed at the end of the coherence principle section, next.

The Coherence Principle

Just as the previous redundancy principle suggests how to increase the efficiency of working memory and decrease the probability of cognitive overload, the *coherence principle* states that individuals learn, retain, and transfer information better when the multimedia instructional environment is free of extraneous words, pictures, or sounds that are likely to interfere with the main instructional message. Introducing irrelevant or extraneous materials into multimedia presentations has the potential to impede learning, retention, and transfer by competing with the instructional materials for limited working memory capacity.

The pedagogical implications of the redundancy and coherence principles are that the learning environment should be kept free of extraneous elements and should focus instead on developing clear and concise instructional messages. This focus on coherence should eliminate the temptation to introduce "bells and whistles" that have the potential to distract users from grasping the relevant instructional messages.

A simple yet effective multimedia instructional environment is the aforementioned *Who Killed William Robinson?* site. This site consists primarily of text and pictures. Its design and implementation are simple and straightforward, with no redundant or extraneous material. Another site that is simple yet effective is the companion Web site for the textbook *Creating Graphics for Learning and Performance* (Lohr, 2003) (http://www.coe.unco.edu/LindaLohr/). Both of these sites contain an abundance of instructional support materials, but are not "tech heavy." Instead, they rely on minimal technology and maximal design.

The Signaling Principle

The *signaling principle* posits that multimedia instruction should utilize graphic elements that provide cues, or signals, to enhance users' journey through the presentation. These cues (for instance, boldfaced words, animated arrows, narration with semantic emphasis) can guide learners' involvement in the multimedia presentation or focus their attention on critical attributes of the instructional environment. This principle is based on the working memory model and cognitive load theory and states that providing learners with cues and assisting them with discerning relevant steps and connections in the material will reduce the number of elements competing for the limited capacity of working memory and help them maintain a manageable cognitive load for processing information.

The signaling principle is critical to the success of facilitating meaningful multimedia learning environments. Technology, particularly in the form of complex Web sites or media-intensive instructional presentations, can overwhelm users and, consequently, distract them from attending to the instructional information in an organized and meaningful fashion. The *DNA From the Beginning* site (http://www.dnaftb.org/dnaftb/1/concept/) provides a good example of signaling. Users are provided with icons they can use to navigate through various components of the tutorial. Additionally, while viewing the animation segments of the site, users are signaled to progress to the next or the previous screen using the appropriate arrows. Within the History section of the BBC Web site, the *A History of Navigation* animation (http://www.bbc.co.uk/history/discovery/exploration/navigation_animation.shtml) provides an excellent example of the signaling principle. The animation provides users with graphic signals—red dots, arrows, and "Enter" markers—to help them navigate throughout the site.

The Contiguity Principle

The *contiguity principle* states that individuals who participate in a multimedia instructional experience in which text or narration and pictures or animation are presented simultaneously in time and space learn, retain, and transfer information better than when the different media are separated temporally or spatially. The rationale behind this principle is that because users' limited working memory capacity is less likely to be overtaxed when the media are presented simultaneously than when their attention is split between multiple media elements in time and space. Thus, learning is enhanced.

Two examples of Web sites in which the contiguity principle is evident, based on the close proximity of the text or narration to the graphics, are the BBC's *Battle of Waterloo* (http://www.bbc.co.uk/history/war/launch_gms_battle_waterloo.shtml) and *World War II* (http://www.bbc.co.uk/history/war/wwtwo/launch_ani_overlord_campaign.shtml) sites. Both sites provide onscreen text-based narration that is located close to the graphics and animations. This propinquity of text and animations provides for concurrent instruction and is less likely to result in cognitive overload.

The Segmentation Principle

According to the *segmentation principle,* it is recommended that when developing multimedia instructional presentations, the narration and animation should be confined to short, user-controlled segments rather than continuous presentations. The segmentation principle contends that when an individual has control over the presentation and can pace the rate of information, cognitive overload is less likely to occur. This level of control allows users to make connections between verbal and visual representations while not overloading the limited capacity of working memory.

Viewing the BBC's *Shackleton's Voyage of Endurance* (http://www.bbc.co.uk/history/games/shackleton/index.shtml) site provides an example of how multimedia instruction can engage users in learning by utilizing short, user-controlled segments. Users can proceed at their own pace throughout the multimedia event, which allows them to read instructions thoroughly and view the accompanying graphics/animations without overloading working memory. The aforementioned *Battle of Waterloo* and *World War II* sites also serve as examples of the segmentation principle, as they, too, provide short, user-controlled segments.

Conclusions

As educators strive to assess the link between technology and learning, the focus of developing pedagogically sound multimedia instruction becomes essential. Research indicates that technology itself has little effect on learning unless the theory that drives the development is pedagogically sound (see Clark, 1983, 1994). The collective works of Mayer, Moreno, and colleagues, therefore, provides educators with a firm theoretical foundation from which to begin to develop pedagogically sound technology-based learning tools that will strengthen the link between technology and learning. In sum, these cognitive principles of multimedia provide educators with specific foundational guidelines.

The multimedia and modality principles challenge educators to utilize both narration and animation in multimedia instructional environments because users benefit from employing both the auditory and visual processing channels. The contiguity principle suggests that these narration and animation components should be presented simultaneously, not divided across time or space. The redundancy principle cautions that when we do provide simultaneous auditory and visual information in a multimedia environment, however, delivering redundant information to either the auditory or visual channels can be detrimental to learning. The coherence principle then extends the redundancy principle and cautions against the urge to incorporate extraneous "bells and whistles" into presentations by providing evidence that eliminating irrelevant stimuli enhances the learning process. The multimedia, modality, contiguity, redundancy, and coherence principles all focus on maintaining a simple, unified multimedia instructional environment.

The signaling and segmentation principles suggest that even simple and unified multimedia instructional environments can be overwhelming to users. Thus, they imply that the recommendation to create simple and unified multimedia instructional environments include the use of explicit scaffolds. For instance, the signaling principle calls for using attentional scaffolds, or cues, within multimedia environments to assist learners in focusing their attention on relevant features and processes. This deliberate use of scaffolding extends to learner control. The segmentation principle fosters the recommendation that learners be given control over the progression of the instruction.

The seven principles we have discussed bridge the gap between the theory and practice of human learning, and provide for the development of technology-based environments with a focus on enhanced learning outcomes. These principles provide educators with firm pedagogical footing on which to develop multimedia learning environments that enhance the learning, retention, and transfer of information.

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Krista P. Terry *is the director of the Multimedia Center and assistant professor in the College of Information Science and Technology at Radford University. Her professional activities and research interests include the design and development of multimedia products for teaching and learning, visual literacy, and the utilization of technology-based products to encourage self-regulated learning and metacognition.* **Peter E. Doolittle** *is head of the educational psychology program in the School of Education at Virginia Polytechnic Institute and State University. He is also the co-director of the Multimedia and Strategy Development Project at Virginia Tech. His research focus includes the investigation of the development of cognitive and metacognitive strategies within multimedia environments.* **Stephanie B. Scheer** *is an assistant professor and instructional designer within the School of Continuing Studies at the University of Virginia. Her duties include working with faculty to design and develop distance and distributed courses and programs. She also collaborates with various units across the university to identify strategic areas for future distance learning course and program development.* **Andrea McNeill** *is a researcher in the instructional technology/education psychology program in the School of Education at Virginia Polytechnic Institute and State University. Her research interest lies in the development of multimedia learning environments designed to enhance learners' cognitive and metacognitive skills.*