Guidelines for Cognitively Efficient Multimedia Learning Tools: Educational Strategies, Cognitive Load, and Interface Design
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Abstract
The field of medical education has consistently embraced new technologies in an attempt to improve the training process of our nation’s doctors. There are thousands of available multimedia learning tools (MMLTs), but no quantitative scale exists to assess their efficiency and overall educational value. The authors review existing literature and suggest guidelines for creating cognitively efficient medical MMLTs.

In 2004, the authors searched PubMed to identify articles regarding multimedia learning, including educational strategies and existing MMLTs. The primary search terms included “multimedia learning,” “cognitive load,” and “surgical education.” The resulting articles were evaluated and reviewed for educational and interface design techniques, and a list of common features was generated. The authors cross-referenced these features with extensive theories of cognitive load to create a list of methods that demonstrated improved learning.

Techniques common to existing MMLTs often neglect to account for theories of cognitive load and may be detrimental to the learning process. The authors outlined important educational considerations and guidelines for the design of effective MMLTs. With large resources being spent to produce MMLTs, more research is necessary to establish successful design techniques. The authors summarized existing research, outlined educational issues in multimedia design, and proposed future directions for study.


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This experience is all too familiar regardless of one’s field or specialty: one comes across multimedia resources and educational software in the quest to learn. Perhaps a colleague’s recommendation or a product’s flashy cover seduced the consumer with promises of “amazing resources,” “the latest in surgical education,” or “lifelike graphics.” One soon learns that the guarantee on the cover does not guarantee information availability or improved learning.

Without a well-designed architecture structure, an application may invite users to waste hours simply learning to navigate the program or playing with the seductive, three-dimensional interface. Hundreds of programs are marketed as potential teaching tools but they rarely reference their educational goals or curricula. Instead, they emphasize graphics and extensive resources.

High-end medical and surgical software is expensive, in both its production and retail costs, yet enthusiastic doctors, residents, and medical schools invest in such products year after year, often to their disappointment. Such multimedia learning tools (MMLTs) are programs that use a computer to combine text, graphics, audio, and video into a concise presentation. Also known as computer-aided instruction programs (CAI) or computer-based learning (CBL), these programs often have links to Internet sites and tools that allow the user to navigate and personalize the interface. According to Fletcher, students retain 20% of what they hear and 40% of what they see, but 75% of what they see, hear, and interact with. A successful learning tool requires both an effective educational strategy and a cognitively efficient interface design to capitalize on the advantages of presenting information in multiple modalities. In order to help educators and students identify cognitively efficient MMLTs, we undertook a review of the pertinent literature. We describe scholarship discussing the importance of design and resources on the efficacy of educational software. We then discuss various learning theories and their effect on MMLT development with respect to issues of students’ behavior and cognition, including attention, working memory, and cognitive load. Based on this review, we recommend a combination of educational strategies, cognitive load theory application, and interface design. We conclude by suggesting a series of guidelines for cognitive efficient MMLTs, along with...
unexplored questions and suggestions for future research.

Searching the Literature
In 2004, we searched PubMed for articles pertaining to medical education software and cognitive load. Our search terms included “computer assisted instruction,” “multimedia learning,” “medical education,” “surgical education,” “memory,” “cognitive load,” “teaching,” “learning,” and “adult cognition.” The search yielded 300 articles pertaining to educational theory, medical education software, and cognitive load. We sorted these articles according to type (e.g., theory, experiment, literature review) and method (e.g., multimedia versus didactic, multimedia versus multimedia). To uncover the most cognitively efficient design techniques, we focused on demonstration articles that clearly described the interface and media comparative articles, which featured randomized controlled tests between interfaces. Studies were eliminated if they failed to address the importance of design or if they offered commentary without a study design.

We grouped articles according to education theory broadly and multimedia software and design topics specifically. Our goal is to raise multimedia awareness with medical educators who are purchasing or designing new software. To that end, we created guidelines for identifying MMLTs that foster active learners and encourage long-term retention of newly acquired knowledge for individuals in all fields of medical education, from design to dissemination. We then dissect educational software into its component parts and describe how each of those parts can be optimized to best benefit medical students.

Educational Theory
Jonassen2 defined knowledge as something waiting to be absorbed and stored, thereby indicating two components of learning: (1) the method of propagating knowledge to the student; and (2) the process by which the student integrates that knowledge into long-term memory. The teacher supplies knowledge that must be properly disseminated to and retained by the student, thus creating and expanding a cache of information.

Behaviorism and constructivism are the two major learning theories on which medical educational systems are based. Each approaches the learning process differently. Behaviorism perceives a learner’s long-term memory as a bank of information that acquires and retains knowledge. This knowledge will decay without repetition and practice.4,5 Motor skills learning theory, used throughout medical education, depends heavily on the tenets of behaviorism in developing and perfecting task skills through repetition. It divides the learning process into three phases: cognitive (knowledge acquisition), associative (skill acquisition), and autonomous (error-free task performance); extensive practice and feedback are critical to successful learning.8 In contrast, constructivism approaches knowledge as a large integrated body of information wherein each new element must fit into a learner’s existing cognitive structures (assimilation).3 It emphasizes that the context in which an idea is presented, as well as the student’s attitude and behavior, affects learning. The constructivist lesson is tailored to challenge students to reflect on their previously held conceptions.7 These two theories lead to drastically different teaching methods. Berger8 differentiates these two types of programs: computer-based tutoring systems (CBTSs) are based on behaviorist theory and teach basic concepts and well-structured information; computer-based learning environments (CBEs) are based on constructivist theory and actively engage students in interpreting and reflecting on problems. CBEs consistently outperform CBTSs with respect to user satisfaction and long-term knowledge retention, whereas curricula for teaching procedural skills and tasks are more effective with CBTSs.8 An understanding of these differences is essential to developing effective MMLTs.

Cognitive load theory is based on information processing assumptions,9 including Mayer’s10 “dual channel assumption,” which states that humans possess separate information processing channels for visual and auditory material (text information is interpreted through the auditory pathway), and the “limited capacity assumption,” which limits the amount of information that can be consumed by either channel at one time (see Figure 1).10 Combined, the human working memory is capable of holding an average of seven items at once. The information retained in and processed by the working memory is referred to as “cognitive load.”11 The number of elements that are consciously or unconsciously attended to by the learner is a necessary component in calculating the total cognitive load of an interface.12 The student must integrate these discreet bundles of information into a limitless long-term memory, the breadth of which determines his or her proficiency with a given subject.13,14

The student’s interaction with newly presented information constitutes the final component of learning. Norman15 describes the student decision sequence as a loop between the student (agent) and the interface (environment). According to Norman, learning is a seven-stage process that begins at goal formation. A learner’s goal is translated into intentions, which she or he uses to develop a detailed set of commands and a plan of action. The plan is executed and the results are compared with the learner’s expectations, based on her or his previous knowledge. The subsequent evaluation and retention of these differences is the act of learning.15 Norman’s theory defines steps that must be individually optimized to enhance the learning experience and increase cognitive efficiency. It supports the theory of constructivism since new information must be integrated into a student’s existing knowledge base. Effective MMLTs can accomplish this through incorporating sound educational theory and interface design.

![Figure 1 Dual channel assumption for processing visual and auditory material. Source: Mayer R. Multimedia Learning. New York: Cambridge University Press, 2001. Reprinted courtesy of Cambridge University Press.](image-url)
the message. Many quantitative studies and the symbolic systems used to convey the media, which deliver the message, MMLT, one must distinguish between When developing or evaluating an Theory Interface Design and Educational Theory When developing or evaluating an MMLT, one must distinguish between the media, which deliver the message, and the symbolic systems used to convey the message. Many quantitative studies neglect to make this distinction, thereby confusing the source of changes in learning. According to Mayer, “it is not possible to separate the effects of the medium from the effects of instructional method. . . . Learning outcomes depend on the quality of the instructional method rather than on the medium per se.” In other words, learning is influenced by instructional methods, not the media by which it is delivered. Therefore, a successful education strategy, one that assists a learner in retaining information in his or her long-term memory despite a limited working memory, must be developed before designing an MMLT. Once the strategy is established, it serves as a framework for the interface design.

Classroom instruction strategies, successful or otherwise, should not simply be built into an MMLT. Instead, teaching strategies need to be translated and transformed, in order to capitalize on the specific advantages available with multimedia. Eva et al. have developed a series of characteristics necessary for effective teachers in a computer assisted learning environment. We have adapted these characteristics into a list of guidelines that create active learners and encourage long-term retention of newly acquired knowledge. We will first discuss the educational merit of each guideline, then present examples from the literature, and translate each guideline into an MMLT design feature.

Creating active, self-directed learners

The teacher is responsible for both supplying information and engaging the student. An active learner is commonly defined as a student who participates in his or her education and demonstrates an increase in self-directed learning. It is important to note that the term “active learner” possesses two components, physical and mental; it is possible to be mentally active and physically passive, or vice versa. We use the term to connote a mentally active learner, one who is interested and involved in the learning activity. We suggest that well-designed MMLTs should use physical interaction, such as mouse-oriented navigation or virtual instruments, to foster mental interest and involvement by the learner. Pintrich and Schunk described the motivation necessary to create an active learner as the abilities to (1) make active choices in the lesson process; (2) demonstrate a willing persistence in the lesson; and (3) not feel overwhelmed by the mental effort necessary to learn. An effective teacher will develop an environment wherein the student is easily consuming and integrating new knowledge by encouraging the learner to use his or her personal resources and actively collaborate with the medium in knowledge construction.

Adding a personal quality to the learning experience has been shown to increase self-directed learning. In an assessment conducted by Marchevsky, group lab sessions were replaced by interactive self-instructional sessions using Web-based technology. The lab sessions were didactic, with little teacher-student interaction, they were conducted by one instructor projecting a demonstration to a group of 12 students. The interactive Web sessions reduced the size of the learning group; three students shared one computer. Attendance increased drastically and students showed a clear preference for the Web-based method. The increased popularity was attributed to a small-group learning environment and a personal interaction with the learning materials.

In surgical education, for example, MMLTs allow passive observers of surgical procedures to become active participants by working through surgical simulations. The learner can practice decision making or surgical tasks free of patient risk and explore the environment using various learning strategies.

Students’ involvement in agenda planning and goal development

Related to the subject of priming the learner, Kirsh proposes that allowing students to participate in the creation of goals fosters their interest in the task at hand. It has been shown that students want to be involved in planning and goal creation. Although we believe that an enjoyable learning environment can increase the incidence of mentally active learners, there is a lack of quantitative evidence that student self-rating correlates with an increase in cognitive efficiency.

Clark cautions against unsupervised goal creation as it may increase the cognitive load by overwhelming the student with potentially irrelevant information. Many learners do not begin with established learning goals, but rather develop them during the lesson.
learning goals are set by a given curriculum and not by students themselves, a pretest is often used instead of explicit goal formation to alert the learner to certain details in the upcoming lesson. This has been shown to improve learning.22

Authentic context

Adopting an authentic context in MMLT instruction ensures that lessons learned in the classroom can be applied to the operating room. By teaching patient management and surgical procedures with real-life scenarios, case-based instruction (CBI) emphasizes this necessary transfer of knowledge. Although test scores show no statistical difference between students taught using CBI and those who learn via traditional lecture methods, there is a marked increase in learner satisfaction with CBI.8 Students claim to have a more pleasant learning experience and often rate themselves as more knowledgeable compared to the self-rating of students in the traditional lecture format.26

Student-sensitive instructional feedback

A characteristic of a good teacher is the ability to monitor students’ responses to material and adjust the lesson accordingly.27 Using an interactive dialogue to encourage students to work through their problems assists instructors to create cognitive models that a student may employ for similar problems in the future.28 In a study conducted by Rogers et al.,29 a feedback lecture format was compared to an MMLT without any instructor feedback. Students participating in the feedback lectures performed better than those using the MMLT, thereby confirming that feedback is essential to learning with or without multimedia intervention. Intelligent computer-based tutorial systems monitor the learner’s performance and provide relevant information; such programs will emphasize a given topic if a student consistently performs poorly in that area. The goal is to develop MMLTs that perform functions similar to the complex role of a teacher. Good interfaces do not simply tell the learner what to do; they provide the environment necessary to assist the learner in productive independent study.23

Eva et al.14 describe a method that has been developed to simplify the software required for MMLTs to have this capacity. Curriculum scripts, also known as “canned talks,” may be written into a program. These scripts are commonly presented as frequently asked questions (FAQs). Students and teachers can be surveyed to discover regular misconceptions and establish the cognitive trajectory (or cognitive workflow) of the average student.14 Questions raised about a given topic or during a lesson can be anticipated and programmed into the MMLT. These “canned talks” can be used pedagogically after the lesson to aid learners in indexing a problem in memory and recognizing connections to other cases. The student can also use them as a reference to clarify any immediate problems. The design structure of allowing access to curriculum scripts or FAQs is important but should be used with caution as full navigational control in an MMLT can impede early learning (which we discuss below).

Social constructivism states that the person-to-person dynamic is an important factor in the student-teacher interaction.3 Clark16 explains that it is the direct presentation of information that results in positive learning effects by reducing supply-related overload when the learner has to search for information. Traditionally, an instructor has been the medium for direct teaching; but MMLTs can now facilitate learning through direct presentation formats. Information anxiety, caused by a gap between what the learner understands and what the learner thinks he or she should understand,31 can be relieved by allowing anonymous access to remedial material. Providing an easily accessible digital library or digital resource center has been shown to positively affect learning.25 In a review of studies assessing the effect of Web-based interventions in traditional print-based curriculum, students with supplemental access to online resources, including study aids and additional cases, scored higher on posttests than did the print-only cohort.32 Resource libraries were used by Diefenbach and Butz,32 Berger,8 Prystowsky et al.4 and Rogers et al.29 in their experimental MMLTs; however, not all of these studies offer quantifiable data regarding the success of resource libraries.

Student-sensitive environments

Similar to student-sensitive feedback, this guideline ensures that the MMLT learning environment adjusts to the learner’s needs. The goal of good software design is to create an environment that complements and simplifies the workflow.23 The user’s cognitive style (e.g., high/low spatial learner) and level of familiarity (e.g., novice, advanced, expert) must be taken into account.
before the lesson begins. Adjustments for different learners can be accomplished through “scaffolding”; this refers to teaching strategies that reduce the cognitive complexities of a task, such as anatomical landmarks in surgical illustrations, and explanations within the program (see Figures 2, 3, and 4). These strategies provide appropriate support to the student; complexity increases accordingly as learning progresses to encourage independence. Cognitive scaffolding is employed at the novice level but becomes unnecessary and distracting for an expert. This is also known as the “guidance fading effect”; as expertise increases, instructional guidance within the MMLT should fade.

Balancing the use of scaffolding across learner levels has proved successful. Uribe et al. demonstrated that students experienced improved learning retention and a smooth learning curve using an endoscopic sinus simulator that employed multiple learning levels. Their simulator had three learner modes: novice, intermediate, and advanced. In the novice mode, the learner was required to refine basic hand-eye coordination and bimanual tasks; the simulator was therefore depicted in an abstract environment and the learner experienced no haptic feedback. In the intermediate mode, the learner performed on a simulated patient with realistic anatomy, higher-fidelity graphics, and anatomical labels. Finally, the advanced mode presented a “real” patient suffering from a real ailment without labels or teaching aids.

**Goal reflection**

Sweller encourages the use of pretesting to prime students for the new knowledge to be delivered (goal development) and posttesting as a codifying agent after instruction (goal reflection). At the end of a lesson, the student should be encouraged to reflect upon the newly acquired information and integrate it into his or her existing body of knowledge. This is part of the constructivist approach to learning, which states that perceptions must be reflected upon frequently. According to the student decision sequence as outlined by Kirsh, goal reflection is an integral part of the learning process. This sequence posits “interpretation in light of expectations” and “compare results to intentions and goal” as its final two steps.

Goal reflection commonly takes two forms: testing and reviewing. Clark cautions that testing can overload the working memory and should be used judiciously, but MMLTs can be programmed to periodically challenge the learner and thereby facilitate integration of the information. In a study by Lipman et al., students required to demonstrate their knowledge through weekly discussion forums outperformed students required to write one midterm paper. The formative group, which offered regular, informal testing, allowed the students to reflect upon the new knowledge in discreet chunks, whereas the summative group did not receive this weekly knowledge consolidation. This experiment did not directly address the difference in testing independent of the other curriculum alterations.

In a formative fashion, post-lesson reviews may be employed within the MMLT to help incorporate new information into learners’ long-term memories. Repetition of information can be used to reinforce previously presented material, but runs the risks of becoming redundant and increasing cognitive load. According to Eva et al., post-lesson “sound bytes” serve three functions: (1) to index the information; (2) to recognize similar cases; and (3) to understand the model. The most cognitively efficient method of reinforcing prior knowledge is to reintroduce the material with different examples, thereby eliminating superfluous information, focusing on goal relevant learning, and encouraging the learner to create a novel way of integrating new information.

In addition to developing an educational strategy, a curriculum designed specifically for the multimedia is another prerequisite for successful MMLTs. To reiterate Mayer’s philosophy, “learning outcomes depend on the quality of the instructional method rather than on the medium.” The most effective approach is to build a new curriculum for the MMLT and resist the urge to “go virtual” by merely translating an existing, lecture-based syllabus to a multimedia interface.

In a randomized controlled study by Grundman et al., two groups of students were each taught two different curricula. Group 1 learned Curriculum A through a lecture-based format and Curriculum B through an MMLT; conversely, Group 2 learned Curriculum A through an MMLT and Curriculum B through lecture. In both cases, the MMLT group consistently outperformed the lecture-based format. By comparing one group against itself, individual learning habits were accounted for. Some experiments have shown no difference in MMLT versus didactic methods, but these trials neglected to create a new lesson plan for the MMLTs. Instead, an existing didactic curriculum was simply translated into an

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**Figure 4** Zoom and scroll functions. Source: Marchevsky AM, Relan A, Baillie S. Self-instructional “virtual pathology” laboratories using Web-based technology enhance medical school teaching of pathology. Hum Pathol. 2003;34(5). Reprinted courtesy of Dr. Marchevsky.
extraneous load is everything else associated with the learning experience. The idea that highly active visual and auditory design techniques enhance the motivation and learning of most students is a common fallacy.16 Sweller et al.3 state that busy screen designs may actually be irrelevant or may cause learning problems. Such seductive features are aspects of an interface that serve no function to the learning task; they are used solely to maintain the learner’s attention.10 This augmentation includes extraneous but appealing frills such as blinking boxes and animated graphics, which can lead to a negative effect by overloading working memory. Simple screen designs that present information in cognitively manageable chunks and focus the learner’s attention on key elements of instruction have proved most successful.16

The balance between the three types of cognitive load is essential to the learner’s experience and can be used to assist in the lesson. High intrinsic components that disseminate complex subject matter, as well as high extraneous components that include abundant seductive details, can inhibit learning if working memory is exceeded9 and attention is directed to nonlearning goals.16 If an MMLT decreases extraneous components and increases germane components, a learner’s attention can be redirected to key elements within the lesson.9 The working memory is capable of retaining seven cognitive items at any given time,11 and the distribution of intrinsic, germane, and extraneous loads within this limitation present an essential factor for MMLT development.

Wainess42 has suggested a method for examining cognitive load in video games: a spreadsheet that documents every cognitive element of a given event or action within the program. Although Wainess employs categories like haptic effects, enemy type, and weapons information, the method may be applied to any immersive multimedia program by creating program-specific categories. In the case of surgical MMLTs, categories may include haptic effects, surgical tool placement, and operating room equipment and personnel.

We may now address guidelines for reducing cognitive load. Each guideline includes examples from previous studies as well as emerging questions posed by the authors and controversies put forth by the existing evidence.

### Synchronize audio and visual information

According to Mayer,10 students learn better when corresponding information is presented simultaneously in space and time. When corresponding words and pictures are separated in time due to lecture constraints or poor program design, cognitive load is increased by forcing the learner to retain a piece of information to understand its context later.10 This is exemplified in Figure 5; the labels have been removed, forcing the user to retain information across space and time. For instructional purposes, all visual and auditory or text information must be available concurrently in order to reduce cognitive load.

Learner preferences must also be taken into account with respect to information presentation. Although it might seem logical to present textual information directly as auditory input through headphones, thereby freeing visual reception for additional information, Marchevsky et al.22 showed that students prefer to read text than listen to it being read. Mas et al.19 compared the effects of listening to reading and found that reading text is more conducive to long-term information retention. This student preference for visual information, however, does not maximize both auditory and visual learning channels to achieve optimal cognitive efficiency; therefore more research is required to determine the best integration of audio and visual information.

### Eliminate multitasking

An MMLT must eliminate any multitasking within the learning experience, specifically when accessing information. Surgical education involves multiple information sources; students often jump between several textbooks, notebooks, anatomy atlases, and so forth, thereby overloading their working memories. Mayer10 calls this impairment in learning the split attention effect, which occurs when a learner must mentally integrate disparate sources of information. Information is better retained when it is directly presented to the learner, replicating a person-to-person interaction.16 A well-designed...
MMLT eliminates the need to collate textbooks, notebooks, illustrations, and other learning tools and places these resources at the learner’s fingertips, thus reducing the germane load of searching for information. In Figure 6, the learner may access any of the learning resources in the lower right-hand corner by scrolling over the books, computer, or expert surgeon. Although in this example these learning resources are easily available, they are imbedded in a highly extraneous design that may increase cognitive load until the user becomes familiar with the interface.

Many MMLTs use various reference resources for the learner, including an electronic notebook, which allows the learner to take notes during the tutorial and bookmark important parts of the lesson plan, lecture notes or procedure descriptions, curriculum scripts, or FAQs as well as to create a repository of relevant cases. These resources may seem necessary for the learning experience but there is no quantitative evidence that they improve learning.

Optimize representations and design an approachable interface
An approachable interface ensures that the learner feels comfortable in the activity space and easily understands all of the representations contained in it. Eva et al. and Norman explain that this is accomplished by replacing random elements with common symbols that are easily recognized by the learner (e.g., a dial or speaker to represent volume) and maximizing visibility, which guarantees that the learner is fully aware of all available options at every juncture. Figure 7 features two consecutive frames of an MMLT that teaches basic and complex hand repair. The tools and functions available at the bottom of the screen are obvious to the learner (e.g., magnifying class for a close-up view). The interface shown in Figure 6 makes the learning resources visible to the learner at all times and the learner can acquire additional information instantly by scrolling over the resource center.

Tool sets, one manifestation of this guideline, collapse certain elements in the virtual environment to reduce onscreen clutter and cognitive load. Tool sets are best employed during advanced stages of learning when the learner is encouraged to explore the program independently. Though not learning tools per se, many commercial programs such as Microsoft Word use this technique by grouping actions into tool-based clusters, including text style and document settings. This way, the program develops a schema that reduces the number of elements presented to the learner at any given time and simplifies the environment.

Maintain a stable learning environment
Despite changes in the content or the learner, the MMLT environment must remain constant. Once a learner has become familiar with navigating the interface, this germane cognitive load is eliminated. In Figure 2, the interface remains the same despite changes in the lesson module. The greatest challenge to becoming accustomed to a new learning environment is a high intrinsic load; students learn to navigate the environment faster (germane load) when the educational content is appropriate to their level (intrinsic load). Learning tools need to balance between all types of cognitive load.

The constant interface across various Microsoft programs, including Word, PowerPoint, and Excel, serves as a common example of a stable environment. Although the programs deal with very different content, they share a common environment. The tools are grouped similarly (e.g., File, Edit, Format) to decrease germane load, the process of becoming familiar with a new program. According to an alternative method of increasing familiarity with a given interface proposed by Kirsh, the learner should be able to prepare, maintain, and rearrange this environment. Mayer has suggested that students control the combination of media input, which leads to a more pleasurable experience. However, these theories are not found elsewhere in the literature. Allowing the learner to influence the media presentation may present additional cognitive elements.

Eliminate redundant information
Repetition of concepts is used to reinforce previously presented material, but can become redundant, thereby increasing intrinsic cognitive load. A delicate balance between redundancy and reinforcement, which strengthens connections between data in the working and long-term memory, must be sought. This difference is often confused in interface design. Mayer’s redundancy principle states that students learn better when they are presented with animation and narration as opposed to animation, narration, and a visual representation of the text. The redundancy of the text overloads the working memory and detracts attention from key information.

MMLTs allow for reinforcement by creating multiple scenarios that deliver similar information and offering concise presentation that assists learners in building a coherent mental representation. Therefore, the learner is
encouraged to create novel methods of integrating new information. Bradley and Postlethwaite refer to this as case conceptualization: offering multiple presentations and solutions for a specific disease process allows the student to properly construct a cognitive schema for dealing with a given surgical or medical problem. Taken one step further, an effective MMLT will aid the novice physician in learning to transfer knowledge to vastly different patients with similar problems. In Figure 6, three patients have a similar diagnosis but present different signs and symptoms; this diversity in presentation helps the learner develop a robust understanding of the condition in question.

Navigational control

Navigational control is the ability to control a computer program, to jump between topics, or to skip sections. According to Kirsh,23 the goal of a good MMLT is to maximize freedom while minimizing complexity. A common misconception is that allowing the learner full control over the MMLT will increase her or his learning and motivation,16 but high navigational control may increase germane load, thereby disorienting and confusing the learner.44 High navigational control only benefits advanced users.18 A successful MMLT must first familiarize the learner with the complete task; a novice should be directed through an entire topic from start to finish to begin the learning process.55 At this level, formal structure is essential,28,46 but as expertise develops, navigational control can be decreased, allowing the learner to explore the program independently. Clark16 explains that restricted navigation for advanced users may impede the learning process by presenting extraneous information that is no longer needed by the expert. Most MMLTs, like the one featured in Figure 2, offer a simple solution to this progression by providing an existing study track, which guides the learner on a preprogrammed, comprehensive path, and the option to jump around within the topics and tests.

Authentic context

An MMLT must optimize the transfer of knowledge from the virtual environment to reality. Computer-based learning environments, no matter how extensively researched and prepared, cannot replicate the experience of performing surgery in the operating room and information can be lost in this transition. Therefore, the successful program will be conducive to bridging the environment change, including realistic graphics and feedback. Many educators have advocated the use of high-fidelity programs and cited a need for face validity, which maintains that the educational value of an MMLT depends on the quality of the animation. The program in Figure 3 features detailed representations of the human hand and allows the user to travel from a superficial perspective to deep within the hand (from skin to muscles to vessels to bone) as well as to change the observation angle. The MMLT featured in Figure 8 attempts to reconstruct the clinical diagnosis experience; a simulated patient with appropriate speech, facial expressions, and other nonverbal communication methods like groaning, is used to emphasize key elements in a patient-physician interaction.

The aforementioned endoscopic sinus surgery simulator tested by Uribe et al.34 demonstrates the value of realism in educational and interface design, but at the advanced mode neglects the transfer of knowledge to reality.34 Similarly, Prystowsky et al.6 tested the efficacy of an intravenous (IV) placement simulator among second- and third-year medical students. Although students’ use of the simulator improved within the program,
this improvement did not translate to placing IVs in real patients. Improved simulation performance can result from increased familiarity with the simulator, but this does not translate to improvement in the operating room. MMLT design will benefit from more studies investigating knowledge transfer from simulator to physical reality as well as ways to control for familiarity with a simulator that improves performance.

Discussion
Multimedia teaching tools are firmly entrenched in medical education generally, and surgical education specifically, and the time has come to further explore the cognitive efficiency of our technological capabilities. We have offered a variety of guidelines regarding educational strategies, cognitive load, and interface design. An MMLT must involve the learner physically and mentally through a variety of educational techniques, many of which we have translated into interface techniques. Technology must minimize cognitive load, thereby focusing attention only on essential, goal-relevant information. Having established important differences between educational strategies and design methods, we will now outline future areas of important research.

How can we best synchronize information?
Presenting information to learners via audio, visual, and tactile channels does not guarantee their interaction with that information. According to Mayer, working memory is more effective, if textual information is presented to the auditory pathway, thereby freeing the visual pathway for complementary content. As we have discussed above, the fact that learners prefer reading text to hearing it read presents an interesting pedagogical dilemma. Which approach, then, should MMLTs adopt? Should they be designed to maximize learning at the risk of losing their audience? Of course not; creative solutions will result from collaboration between medical educators and multimedia design experts. Formal education studies are necessary to ensure that resources are spent where they are most successful.

Studies of different learning styles suggest there may be a benefit to dividing the screen into different components including text, images and utilities; this provides options to the learner without drastically affecting content. If the environment is divided into a standard template, the learner can interact with all available information by using interactive fields for complementary learning and reducing cognitive load. A divided interface is featured in the Virtual Learning Interface by Goldberg and McKhann, which presents a video of a lecture in parallel with an animated supplement, similar to the presentation in Figure 2. This method also allows the learner to swap fields or include other aspects of the program (e.g., animated lecture and parallel lecture notes), which allows each learner to create a personalized, tailored environment while the program maintaining a strict educational framework.

Is the navigation of images necessary?
According to the theories we have presented, the advanced learner should have extensive control over the MMLT environment, including navigation of images presented in that environment. However, in a study of medical students’ use of Web-based pathology laboratory tutorials Marchevsky et al. discovered that few of their study participants took advantage of extraneous options, including zooming and scrolling functions. Participants claimed that the available images were sufficient (see Figure 4). This issue is closely related to the navigation of video content and whether or not the learner should be able to exercise slow motion and rewind capabilities. Although these may seem like essential options, it is uncertain how often learners actually use them. Thoughtful, formal evaluation of the return from these costly features is needed.

Do high-fidelity programs increase cognitive efficiency?
With better technology comes the insatiable urge to use it, leading to the proliferation of high-fidelity programs, such as the interactive hand in Figure 3. This program offers a 360-degree view of the human hand, controlled by the user. Although this seems to offer educational benefit, Garg et al. conclude that this feature is merely aesthetic. In an experiment testing the educational potential of two-dimensional image storage, subjects were given the choice to study either key viewpoint images or full rotational access. Subjects chose to use key viewpoints, similar to those offered in a textbook, despite the full view option. The study also demonstrated that learner control of multiple orientations offered no advantage over access to orientations close to key views.
In a study investigating benchmark fidelity on endourological skills, Matsumoto et al. found no significant differences in the performances of students who trained on a low-fidelity device and those using a high-fidelity tool. Subjects randomly selected to the high-fidelity group practiced with an interactive MMLT, while those in the low-fidelity group used a model consisting of an inverted cup and two embedded straws in a portable plastic case; the cost of the two devices differed by over $3,000. At this date, the educational benefit of advanced graphics is unclear. More research is needed to explore the relationship between fidelity of characters, motion, anatomical detail, and the transferability of knowledge and skills from simulation environments to those of real practice.

Is the virtual companion necessary or beneficial?

In a study of medically oriented MMLTs developed for nonmedical learners, subjects voiced a desire for a “virtual companion,” an anthropomorphic figure similar to an instructor that guides the learner through the environment, emphasizing key points and offering assistance along the way. Sweller explains that the overall goal of an MMLT is to disseminate previously developed knowledge structures by exploiting nonverbal communication that is often reserved for human-to-human interaction. But is such a feature best reserved for human-to-human interaction? More research is needed to explore the relationship between fidelity of characters, motion, anatomical detail, and the transferability of knowledge and skills from simulation environments to those of real practice.

Multimedia learning tools have been employed at all levels of learning in our technophile society, but their actual effectiveness is difficult to quantify due to the intimate relationship between educational theory and interface design. Borrowing from Mas et al., we recommend that medical educators “use multimedia rationally.” We have initiated studies that address some of the above questions. Through additional research, the guidelines we have suggested here can aid program designers in producing more effective, less expensive MMLTs and drastically alter the medical educational landscape. We hope others interested in medical and surgical education will join in this effort.

Statistics regarding additional learning resources incorporated into MMLTs, including the electronic notebook, lecture/surgery notes, or FAQs, are scarce. Baumlin et al. conducted trials of EMCyberSchool, an Internet-enabled computer-assisted instruction tool designed to supplement a curriculum for senior medical students in emergency medicine with additional cases and images. The study showed the program’s educational success without addressing the role of the additional resources in this success. Although many educators consider additional materials essential to learning, learners’ usage rates of these features have not been adequately studied. Medical MMLT developers assume that more is better, but without strong evidence as to the utility and efficacy of additional resources, money, time, and effort may be wasted by including them. Further research is necessary to discover what groups of learners benefit most from which resources.

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