Implications of Designing Instructional Video Using Cognitive Theory of Multimedia Learning

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Introduction

The advancements in the information and communication technologies resulted in renewed interest of the educational community in multimedia learning materials. Much of the recent discussion has focused on the educational benefits of multimedia to improve students' learning. In education, multimedia takes different forms, including words and pictures, and can present as printed or spoken text. The pictures can be presented in static form, such as illustrations, photos, diagrams, charts, or maps, or in dynamic form, such as animation or video (R. E. Mayer, 2011). The use of instructional multimedia can also take many formats, such as students watching and listening to a narrated animation, reading a science textbook, playing an educational video game, attending a Power- Point presentation, or watching and listening to educational video.

Although the use of multimedia in teaching and learning increased during the last two decades, one specific multimedia type—educational video—has been described as important in helping students acquire knowledge due to its capability to present learning content dynamically and the use of multiple representations, such as still and moving images, audio, and animations (P. Chandler, 2009a). Recent studies found that the use of video has increased over the past decade to become the third most popular genre for learning and reached 38% of adult Internet users (Purcell, 2010). Since the advent of television, many empirical studies on the use of dynamic audiovisuals in education have demonstrated that students not only prefer educational video over text, but are also more likely to gain deeper learning from video than from words alone (Baggett, 1984; R. Mayer, 2002, 2003, 2005; R. Mayer & Moreno, 2002; Salomon, 1984; Shepard, 1967; C. Wetzel, P. Radtke, & H. Stern, 1994). Researchers suggested that because audiovisuals contain two representations: visual that conveys information about objects and its relation to other objects, and verbal that communicates abstract meaning and special attributes of this information. A combination of both representations should increase the learning effect (e.g., Guttormsen, Kaiser, & Krueger, 1999; Hegarty, Kriz, & Cate, 2003; Lowe, 1999).

Moreover, watching the changes of visual information, rather than mentally inferring this information, helps learners to free up cognitive resources to organize and integrate information more effectively and efficiently (Hegarty, et al., 2003; Schnotz & Rasch, 2005). Dynamic visualizations are also perceived by students as useful due to their ability to present content that is difficult to verbalize but easy to demonstrate (e.g., P. Chandler, 2009b). For example, videos help students observe complex natural processes (e.g., the formation of lightning; R. Mayer & P. Chandler, 2001), mechanical systems (e.g., an electric motor; R. Mayer, G. Dow, & S. Mayer, 2003), procedures involved in performing a task (e.g., first aid, Arguel & Jamet, 2009; or solving probability calculation problems; I. Spanjers & Van Merrienboer, 2010), laboratory experiments, and field observations (DiPaolo, 1995).

A major assumption underlying this line of work is that although humans can construct a mental representation of the semantic meaning from auditory or visual information alone, instruction that is presented in both formats, provides complementary information that is relevant to learning (Baggett, 1984).

Objective

During the last decade, cognitive researchers identified three major challenges facing the use of multimedia materials in instruction. The first challenge is the inclusion of extraneous content that competes with the essential information for limited cognitive resources. Researchers found that including extraneous material in multimedia materials may cause learners to engage in extraneous processing—by using their processing capacity to attend to and process material that is not essential to building a mental model of the to-be learned content. Therefore, learners given an expanded multimedia lesson may have less cognitive capacity for processing the essential material and therefore may be less likely to build a learning outcome that can be used to generate useful answers on a test (R. C. Clark & Mayer, 2011). For example, empirical studies examined the effect of including extraneous content in multimedia found that students performed better on a problem solving transfer test after receiving a concise lesson, rather than an expanded lesson (Harp & Mayer, 1997b, Experiment 1; 1998, Experiments 1, 2, 3, and 4; Mayer, Heiser, & Lonn, 2001, Experiment 3; R. Mayer, 1996; R. E. Mayer, W. Bove, A. Bryman, R. Mars, & L. Tapangco, 1996, Experiments 1 and 2; R. E. Mayer, J. Heiser, & S. Lonn, 2001; R. E. Mayer & Jackson, 2005, Experiments 1a, 1b, and 2; Moreno & Mayer, 2000, Experiments 1 and 2).

The second challenge facing the use multimedia learning materials is when the lesson contains some interesting but extraneous details, and it is not possible to delete the extraneous material. In this situation it is difficult to focus students' attention on essential information. Therefore, it is better for students to learn from a multimedia lesson when essential words are highlighted or signaled to help guide their attention toward the essential information. Highlighting the essential information in the lesson could take different forms, such as by adding an overview sentence at the start of the narration that restates the main ideas, adding headings for each section in the narration that correspond to the main ideas in the overview, and emphasizing main ideas in the narration by stressing them vocally. Empirical evidence supports these methods found in many studies involving both computer-based lessons and paper-based lessons, where learners who received signaled lessons performed better on transfer tests than students who received non-signaled lessons (Harp & Mayer, 1998, Experiment 3a; Mautone & Mayer, 2001, Experiments 3a and 3b; Stull & Mayer, 2007, Experiments 1, 2, and 3).

The third challenge facing multimedia learning content occurs when the learning content is dynamic and too complex and the designer can't delete the material because it is needed for the learner to build a coherent mental representation. Complexity is determined by the number of elements and the relations between them. This situation is likely to cause learner's cognitive system to be overloaded by essential material and that demands of essential processing overwhelm the learner. Researchers found that to overcome this problem, the multimedia content should be broken into segments. According to CTML, segmentation allows the learner to fully represent each part of the presentation before moving on to the next part. For example, in three experiments involving computer-based lessons on lightning and electric motors, students who received segmented lessons performed better on transfer tests than did learners who received continuous lessons (R. Mayer & P. Chandler, 2001, Experiment 2; R. Mayer, et al., 2003, Experiments 2a and 2b).

Theoretical Framework

Cognitive Theory of Multimedia Learning (Mayer, 2001) and Cognitive Load Theory (Sweller, 1999) provide a useful framework to explain the cognitive processing during learning from educational video.

The central issue in this framework is how to help people learn. According to CTML, instruction works by priming appropriate cognitive processing in the learner during learning that is, by guiding the learner's selecting of relevant material, organizing of the material into a coherent cognitive representation, and integrating of the representation with other relevant knowledge. Based on this approach, the central challenge of instructional design is how to encourage learners to engage in appropriate cognitive processing during learning while not overloading the processing capacity of the verbal or pictorial channel. To overcome this challenge, multimedia designers should follow three key elements in the learning materials (a) help learners to reduce extraneous processing—cognitive processing that does not support the instructional goal and is attributable to confusing instructional design; (b) help learners to manage essential processing—cognitive processing needed to mentally represent the incoming material and that is attributable to the complexity of the material; and (c) help learners to foster generative processing— cognitive processing aimed at making sense of the incoming material, including organizing it and integrating it with prior knowledge (R. Mayer, 2005; Sweller, 1999).

According to this framework, learners acquire information through three cognitive components of the cognitive system, sensory register, working memory (WM) and long-term memory (LTM). First, information is received by sensory registers (e.g., eye, ear), and store it in the sensory store that briefly holds raw, unprocessed information until the stimulus pattern is recognized or lost. Pattern recognition involves the matching of stimulus information with previously acquired knowledge (Moore, Burton, & Myers, 1996). Sensory registers consist of two separate channels: one for the processing of visual or pictorial information and one for the processing of auditory or verbal information (Baddeley, 1986; Baddeley & Logie, 1999; Paivio, 1986). Because each channel has a relatively limited capacity, it is easy for the cognitive system to become overloaded if more than a few segments or chunks of novel information are processed simultaneously (Baddeley, 1986; Miller, 1956; Sweller, 2003). Presenting unique information in both visual/pictorial and auditory/verbal formats allows the learner to use both information processing channels at the same time and enables the learner to construct integrated mental models that make the retrieval of the information more likely (Paivio, 1986; Plass, Chun, Mayer, & Leutner, 1998).

The information is then retained in the working memory (WM). Klatzky (1975) defined WM as a work space in which information may be rehearsed, elaborated, used for decision making, lost, or stored in the third memory structure. Due to these functions, working memory has also been equated with consciousness (J. Sweller, Van Merrienboer, & Paas, 1998). WM is described as the bottleneck of human cognitive system having very limited duration and capacity. It can store information for only about 30 seconds (Peterson & Peterson, 1959), and only about seven, plus or minus two, information segments (chunks) can be processed in it at any given time (Miller, 1956). The exact number of items to be processed depend upon a number of factors, such as age, level of fatigue, expertise in the content area, complexity of information, and priming (e.g., Baddeley, 1992; A. Baddeley, Thomson, & Buchanan, 1975; Stoltzfus, Hasher, & Zacks, 1996). WM can maintain information longer than the sensory store through a process known as maintenance rehearsal, which recycles material over and over as the cognitive system processes it. Without rehearsal, the information would decay and be lost within seconds. Research has shown that this limited pool affects everything from decision making to the sizes of visual images that can be processed.

The third component of the human cognitive system is the long-term memory (LTM), which is described as a complex and permanent storehouse for individuals' knowledge about the world and their experiences in it (Baddeley, 1986; Moore, et al., 1996; Wyer, Schank, & Abelson, 1995). LTM stores information that has been processed and deemed relevant by WM in the form of schemas (also referred to as schemata). Schemas are memory structures that organize a large number of information elements into a single element. For example, the schema of a house may include such information elements as construction materials, room types and layout, home appliances, etc. A major distinction between WM and LTM lies in that LTM has no known capacity limitations (Paas & Merrienboer, 1994; J. Sweller, et al., 1998). Interactions between WM and LTM allow humans to engage in cognitive activities that can range from the simple memorizing of facts to advanced applications; transferring knowledge; and applying skills, which are characteristic of an expert. Novice learners are typically engaged in learning by employing sensory channels within WM to build new schemas in LTM.

Based on this framework, human verbal and visual perception is extremely selective, and learners can focus their attention only on a small amount of auditory/verbal and visual/pictorial presentation at once, and only a small portion of that information can be subsequently processed in WM (Baddeley, 1992). The elements, that learners will select to process are determined by several factors, such as the element's relative importance and the level of detail (Winn, 1993). The analysis of the characteristics affecting the learners' attention helps to identify the properties that enable students to direct their attention to the most relevant elements of the learning materials and to predict the conditions under which the audiovisual presentation may be effective (de Koning, Tabbers, Rikers, & Paas, 2009).

While learners' cognitive capacity available in a specific learning situation is limited and has to be distributed over several cognitive and metacognitive processes, the content to be learned induces more demands on this capacity depending on its intrinsic complexity and element interactivity (i.e., intrinsic load) (Paas, Renkl, & Sweller, 2004). For example, learning individual vocabulary units or words of a foreign language is intrinsically less complex than learning grammar because the latter requires consideration of the interaction of different parts of speech, and is, therefore, intrinsically more complex (Van Merrienboer, Kirschner, & Kester, 2003). Furthermore, different types of learning materials and different instructional designs require different amounts of cognitive capacity, independent of the content of the learning material. The capacity needed to meet these design and presentation related requirements is assumed to make no contribution to the learning process because it has to be used to compensate for a "bad" instructional or informational design (e.g., too much text on a PowerPoint slide), resulting in extraneous demands on the WM (i.e., extraneous load). Finally, cognitive capacity is needed for active knowledge construction, such as schema integration or automation. This type of cognitive load is assumed to be the key factor in the understanding and the storing of the learning material and, thus, it is considered to be germane to learning (i.e., germane load). Cognitive Load Theory proposes that the total available capacity is limited and that the three types of cognitive load (i.e., intrinsic, extraneous, and germane) are additive in their combined capacity requirements. Therefore, the main implication for the design of multimedia learning materials is that these materials and activities should be designed with minimal extraneous load requirements and maximal potential for germane cognitive processing (Brünken, Steinbacher, Plass, & Leutner, 2002).

Multimedia Design Manipulations Based on CTML

These theoretical considerations have resulted in the development of various design principles that take into account the processing limitations of WM to manage the cognitive load demands associated with multimedia learning content (Mayer, 2001; F. Paas, Tuovinen, Tabbers, & Van Gerven, 2003). These principles were examined in a variety of learning scenarios, resulting in specific prescriptions regarding which and when of these design principles work, for whom, and for which types of learning materials (e.g., Mayer & Moreno, 2003; Plass, et al., 1998; Plass, Chun, Mayer, & Leutner, 2003).

The following section will review the existing research on three of these multimedia design principles selected for this study: segmentation, signaling and weeding.

Segmentation

Segmentation is a design principle in which the learning materials are divided into short units and distributed over series of instructional events, such as topics or lessons referred to as segments (Clark, Nguyen, & Sweller, 2006). In video, segments are chunks of dynamic visualizations that have an identifiable start and end point and which are distinguished by inserting pauses between different segments (J. Boucheix & H. Guignard, 2005; B. Hasler, B. Kersten, & J. Sweller, 2007; Mayer & Chandler, 2001; Mayer, Dow, & Mayer, 2003; R. Moreno, 2007b; I. Spanjers, Van Gog, Van Merrienboer, & Wouters, 2011). The purpose of this method is to allow learners to intellectually digest manageable pieces of learning materials before moving on to the next segment of information (Sweller, 1999). Segmentation has been described as a possible solution to the problem of information transiency educational video (I. Spanjers & Van Merrienboer, 2010).

Several studies examined the effects of segmentation of dynamic visualizations on learning and found that this method is helpful for novice learners, when the learning material is conceptually complex and when the pace of the presentation is rapid. For example, Mayer, Dow and Mayer (2003) compared the learning outcomes of students who learned about electric motors using a simulation game in which they interacted with an on-screen agent. In the continuous version, students viewed a continuous animation showing how the electric motor operates. In the segmented version, a list of questions appeared corresponding to each segment of the narrated animation. Results showed that the segmented group outperformed the continuous group on the test of knowledge transfer. Boucheix and Guignard (2005) compared the cognitive effects of different versions of a slideshow with learners' control. One version of the slideshow allowed students to start the next slide or repeat the previous slide and two other versions allowed learners to control the rate of the presentation (fast and slow). The researchers found larger gains from pretest to posttest for students using the segmented version of the slideshow.

Three other studies explored multimedia designs featuring learner control and segmentation (B. Hasler, et al., 2007; Mayer & Chandler, 2001). In these designs, the presentation stopped automatically at the end of each segment, and the participants could decide when they wanted to continue with the next segment. Moreno (R. Moreno, 2007a) conducted two experiments that had the participants view a segmented version of an exemplary classroom video (experiment 1) or an animation demonstrating teaching skills (experiment 2). In both experiments participants reported investing less mental effort and perceived the learning materials as less difficult than those who learned from non-segmented versions of the material. Mayer and Chandler (2001) examined the effects of a segmented version of a narrated animation that explained lightning formation using sixteen segments. Each segment contained one or two sentences of narration and approximately eight to ten seconds of animation. Investigators found that although students in both groups received identical content, students who viewed the segmented presentation performed better on subsequent tests of problem-solving transfer than did students who viewed a continuous presentation. Finally, Hasler et al. (2007) compared four versions of their learning material on the causes of day and night: a segmented animation, a non-segmented animation that students could pause at each moment (i.e., with learner control), a non-segmented animation without learner control, and a non-segmented audio-only version without learner control. Learning time was equalized for the conditions by having students study the learning material repeatedly until ten minutes were over. Their results showed that learners who studied the segmented animation or the animation that they could pause performed better on test questions than students who studied one of the two other versions of the material, even though most learners who could pause the animation did not use that option. Although learners in these three studies had less control than the learners in the studies of Boucheix and Guignard (2005), Spanjers et al. (2010) suggested that learner control might still have influenced the effects of segmentation.

Segmentation was also found to help define event boundaries. That is, rather than relying on students' ability to mentally segment the presentation by inferring the topic shift and the presentation structure, designers of the learning materials do it for them (I. Spanjers & Van Merrienboer, 2010). It was hypothesized that segmentation might enhance learning by aiding students in perceiving the underlying structure of the process or procedure. For example, Catrambone (1995) compared four groups, which differed on whether or not a label for a particular calculation sub-step was provided (i.e., providing meaning to the step) and on whether or not that calculation sub-step was placed on a separate line (i.e., cue of what constituted a step). Learning outcomes were higher, and students mentioned sub-steps more often in their description of the calculation procedure when a label was provided, when the step was visually isolated or both the label was provided and the step was isolated, compared with the control condition in which no segmenting and cueing were provided.

The effect of segmentation on students with different levels of prior knowledge is another relevant area of study. For example, Spanjers et al. (2011) investigated the effects of segmented and non-segmented animations on probability calculation procedures on the learning of students with different levels of prior knowledge, and their segmented animations automatically paused after each segment and automatically continued after two seconds. A significant interaction was found between the effects of segmentation and prior knowledge: students with lower levels of prior knowledge learned more efficiently from segmented animations than from non-segmented animations, while students with higher levels of prior knowledge learned equally efficiently from non-segmented and segmented ones (cf., the expertise reversal effect; Kalyuga, 2007). One potential explanation for this effect is that learners with higher levels of prior knowledge might rely more on their existing knowledge structures of the domain and not use segmentation as temporal cues to break up the content into relevant chunks. Similar findings were reported by Boucheix and Guignard (2005) that show that students with higher levels of prior knowledge do not need additional guidance through segmentation because for students with higher levels of prior knowledge, the amount of cognitive resources they can devote to cognitive activities with a positive effect on learning is reduced when they have to reconcile the instructional guidance with the guidance given by their available cognitive schemas (Kalyuga, 2007).

Signaling

The second design principle is signaling. Learning materials designed using this principle help students focus on relevant content in audiovisuals through several methods: increasing the luminance of specific objects in a visual display (e.g., de Koning, Tabbers, Rikers, & Paas, 2007), changing a word's font style to boldface in a text (e.g., Mautone & Mayer, 2001), flashing to connect related elements (Craig, Gholson, & Driscoll, 2002; Jeung, Chandler, & Sweller, 1997), giving related elements the same color (Kalyuga, Chandler, & Sweller, 1999), providing orienting cues like gestures as guides to related elements (Lusk & Atkinson, 2007), or by adding an outline and headings indicated by underlining and spoken emphasis (Mayer, 2005). Although signals do not provide any substantive information, research found that people learn more deeply from audiovisuals when essential material is highlighted or cued (Mautone & Mayer, 2001; Meyer, 1975; Tversky, Heiser, Lozano, MacKenzie, & Morrison, 2008). De Koning et.al (2009) identify three main functions of signaling that might be related to distinct perceptual and cognitive effects: (1) guiding learners' attention to facilitate the selection and extraction of essential information, (2) emphasizing the major topics of instruction and their organization, and (3) making the relations between elements more salient to foster their integration.

Studies on text comprehension have consistently shown that signals improve the recall of the content they emphasize (e.g., Cashen & Leicht, 1970; Dee-Lucas & DiVesta, 1980; Lorch & Lorch, 1996). Other studies showed that memory for uncued content is unaffected (Foster, 1979), inhibited (Glynn & DiVesta, 1979), or sometimes even enhanced (Cashen & Leicht, 1970). These findings suggest that emphasizing particular content may guide learners' attention to essential information but does not necessarily reduce attention for uncued information (de Koning, et al., 2009). Although research on signaling in text-processing produced mixed results, signaling in static illustrations was found to guide students' attention and improve learning (Tversky, et al., 2008). For example, several studies found that redirecting the learners' attention to critical elements of the problem using, for example, color highlights led to more correct problem-solutions than studying the same diagrams without such cues (Thomas & Lleras, 2007). This result is in line with Park and Hopkins' (1993) recommendation to use perceptual features (e.g., color, motion) to guide learners' attention to critical information during visual instruction (de Koning, et al., 2009).

Signaling was also found to reduce extraneous cognitive processing during instruction as indicated by performance on a secondary task and learning outcomes. Evidence of this function comes from a study on text processing, where students read a signaled or a non-signaled text while at the same time their reaction times to a secondary task were measured as an indication of cognitive load (Britton, Glynn, Meyer, & Penland, 1982). Results indicated that texts containing cues about relevant concepts and their relations required less cognitive resources to process than texts without cues. Loman and Mayer (1983) compared students in two groups who studied signaled or non-signaled texts and showed that students in the signaled condition experienced lower cognitive load causing them to construct better representations of the content, as indicated by better retention and transfer performances. The authors suggested that signaling the text reduced students' visual search and the unnecessary load associated with locating relevant information, which freed up WM resources for genuine learning activities.

The effects of signaling were also examined in learning from audiovisuals (Mautone & Mayer, 2001) who found that dynamic cueing may improve learning. For example, Lowe and Boucheix (2007) examined a form of "continuous cueing" by presenting learners with an animation of a piano mechanism with a dynamic spreading color cue. The visual colored path continuously provided a close temporal and visuospatial similarity to related auditory information and occurred synchronous with the visualization of the main causal chains. Results showed that signaling improved students' understanding of the kinematics and functional model of the piano mechanism, suggesting that the spreading color cue effectively enhanced germane cognitive processing (de Koning, et al., 2009). The investigators indicated that the eye movement data collected in the study suggested that the continuous cue produced an altered viewing pattern, that is, it introduced a new way of viewing the animation, which may have stimulated learners to cognitively process the content more deeply. De Koning, et al. (2009) suggested that the success of this type of cueing may lie in the fact that it served not only the function of guiding attention to essential information but also functioned to relate elements within a representation (i.e., it made temporal relations more explicit), which may have increased cognitive engagement and subsequent understanding of the animation.

In another study that used signaling to guide attention to essential information, De Koning et al. (2007) asked learners to study a non-narrated complex animation illustrating the dynamics of the main processes of the cardiovascular system. One group studied the animation with a visual color contrast cue highlighting one specific process (i.e., the valves system), whereas another group studied the animation without visual cues. Results indicate that emphasizing particular content significantly improved comprehension and transfer performance on both the content that was cued as well as on the content that was uncued. No differences were found in the amount of cognitive load, but given the higher learning performances in the cued condition, the investigators argued that visual cueing leads to a more effective use of WM resources. To explain these results, De Koning, et al. (2009) suggested that the effectiveness of visual cues is dependent on the complexity of the instructional animation and only improves learning if learners need cues to assist them in constructing a coherent representation. This suggestion could be found in line with the study of Jeung et al. (1997) that has demonstrated that the degree of visual complexity of instruction seems to be a crucial factor for the effectiveness of cueing.

Despite the generally positive effects of signaling in text and animations, other research demonstrates that visual cueing does not always improve learning. Within this body of work, researchers have focused on the effects of graphical cues on the comprehension of a visual-only animation without text. For example, in an eye-tracking experiment, Kriz and Hegarty (2007) compared two groups of students that studied a user-controlled animation showing the steps in a flushing cistern mechanism using arrows to guide attention to essential information and arrows to emphasize causal relations between components or inferences. Results revealed no evidence of the benefit of cueing on comprehension. Furthermore, while the arrow cues were found to direct students' attention to more relevant information, it did not result in a better understanding of the information presented in the animation than studying an animation without visual cues. Other researchers used eye tracking and verbal reporting techniques to identify the underlying mechanism of attention cueing. For example, a study by De Koning et al. (2007) involved learning from an animation of the cardiovascular system in which none, one, or all of its subsystems were successively cued using a spotlight cue (i.e., luminance contrast). Results were similar to those of

Kriz and Hegarty (2007) in that the spotlight cues effectively captured students' attention, however they did not improve the understanding of content.

Research also found that improper use of signaling can even increase the cognitive load of the learner. In a study by Moreno (2007b), prospective teachers studied effective teaching skills with, or without visual cues. In the cueing condition, the critical teaching skills that were visualized in the animation were highlighted in a bright red color on a step laddered list containing the labels for each skill. The labels accompanying the skills in the animation were used to guide students' attention to essential information and relating connected elements between representations. Results showed that the cues did not improve learning performance. Moreno (2007b) suggested that cueing may have forced learners to spatially split their visual attention between the animation and the highlighted labels that were presented side-by-side and therefore may have interfered with the learning process.

Although some studies demonstrate that signaling does not always facilitate learning, Mayer (2001) suggested that signals should produce a strong effect under certain conditions: (1) for students who do not normally pay attention to the outline structure of a passage, (2) for passages that are poorly written, (3) when the goal of instruction is promoting retention of the major conceptual information and creative problem solving, and (4) when the teacher wants to help students recognize topic shifts.

Weeding

The third component of the SSW design model is *weeding* or removal of irrelevant content in order to reduce the negative cognitive effects of the extraneous materials in audiovisuals. Mayer & Moreno (2003) suggested that learning materials are better understood when they include fewer rather than many extraneous words, visuals, and sounds and found that students learn better from a concise summary that highlights the relevant words and pictures than from a longer version of the summary. The inclusion of irrelevant information often primes learners to engage in incidental processing and diverts the limited cognitive resources, which may hinder learning (Brünken, Plass, & Leutner, 2004).

Tabbers (2002) categorized the extraneous information in the learning materials into three kinds. First, it is the information that is irrelevant to learning but interesting to keep students motivated. Multiple studies found that these extraneous details often do more harm than good to learning (Harp & Mayer, 1997a, 1998; Mayer, et al., 2001; Moreno & Mayer, 2000). Second, redundant information that is derived from other information elements in the presentation was also found to have a negative effect on learning. Redundant information includes presenting text or a picture accompanying an animation both on-screen and as a narration (Kalyuga, et al., 1999; Kalyuga, Chandler, & Sweller, 2000; Mayer, et al., 2001; Mousavi, Low, & Sweller, 1995), adding explanatory text to a diagram that could be understood on its own (Chandler & Sweller, 1991), or adding the full text to a summary of a text (R. Mayer, 1996). Third, redundant information that is familiar to learners who develop expertise in a learning domain can be detrimental to learning. For example, an expert in a certain area will not need the information that is essential to a novice. Researchers suggest that when experts are forced to process information that is already familiar to them, extraneous cognitive load is increased due to processing redundancies, which leads to negative influence on learning (Kalyuga, Chandler, & Sweller, 1998; Kalyuga, et al., 2000).

Research on weeding shows that adding interesting but conceptually irrelevant content in text-based materials reduces the amount of relevant material that the learner remembers (Garner, Gillingham, & White, 1989; Hidi & Baird, 1988; Wade & Adams, 1990). For example, in a study using a free recall test, Mayer (2003) found that students given a weeded version of a text produced 59 facts, while students given the original version produced 35 facts, indicating a 68% improvement for the weeded passage. Students given the concise version also performed better on the comprehension test, answering 46 percent of the questions correctly, whereas students given the original version answered 37 percent of the test items correctly.

Extraneous materials should be excluded from multimedia presentations, even if this extra information contains interesting and potentially motivating elements, such as illustrations or music or sounds (Harp & Mayer, 1998; Moreno & Mayer, 2000). A number of experiments have shown that removing superfluous information from multimedia instructions resulted in more effective learning. For example, in two experiments, Moreno and Mayer (2000) compared two versions of a learning system; one was delivering information as narration and animation, the other delivering the same information with the same narration and animation, but adding interesting yet irrelevant sounds and background music. Investigators found strong evidence for a negative effect of background music on knowledge acquisition. In both experiments, students working with the material without background music outperformed the learners working with the material containing background music. In a similar study, Mayer et al. (2001) demonstrated that adding interesting but conceptually irrelevant video clips to a multimedia explanation can result in negative effects on students' understanding of the explanation. The investigators found that students who viewed video clips added within the narrated animation or placed before the narrated animation displayed poorer problem-solving transfer performance than students who received no video clips.

In computer-based instruction, Mayer (2008) indicated that students performed better on a problem-solving transfer test in 13 out of 14 experiments involving topics like lightning, ocean waves, and brakes after receiving a concise lesson rather than an expanded lesson (Harp & Mayer, 1997a, 1998; Mayer, et al., 2001; R. Mayer, W. Bove, A. Bryman, R. Mars, & L. Tapangco, 1996; Moreno & Mayer, 2000). Mayer explained that including extraneous material caused learners to engage in high levels of extraneous processing. The extraneous material competes for cognitive resources in WM and can divert attention from the important material, disrupt the process of organizing the material, and can prime the learner to organize the material around an inappropriate theme. Mayer (2001) identified three complementary versions for removing the extraneous content from learning materials: 1) student learning is lessened when interesting but irrelevant words and pictures are added to a multimedia presentation; 2) student learning is decreased when interesting but irrelevant sounds and music are added to a multimedia presentation; and 3) student learning is improved when unneeded words are eliminated from a multimedia presentation.

Limitations Associated with Learning from Video

Despite the apparent advantage of multimedia, including instructional video, in presenting the learning content in auditory and pictorial formats, cognitive researchers argue that multimedia materials require high levels of cognitive processing to synthesize the visual and auditory streams of information and to extract the semantics of the message (Homer, Plass, & Blake, 2008). According to cognitive science researchers, learning depends on the efficient of student's cognitive system during three cognitive processes (a) selecting process, attending to the relevant incoming material; (b) organizing process, organizing the incoming material into a coherent mental representation; and (c) integrating process, relating the incoming material with existing knowledge from long-term memory (R. E. Mayer, 2011). Furthermore, the cognitive demand increases when students are novices in the knowledge domain and lack appropriate prior knowledge to guide their attention (Moreno, 2004; Sweller, 1999). The simultaneous processing of auditory and visual information place higher demand on student's cognitive system, which may exhaust the limited cognitive resources available for processing the relevant materials of the lesson. The result is that learning and problem solving may be impaired (Chandler & Sweller, 1991).

Research Questions

The present study builds on prior research in two important ways. First, we examine how the SSW design principles in educational video affect students' cognitive load and learning outcomes as compared to students learning from a non-SSW version of the same video. The second contribution is to outline a theoretical and empirical basis for the domain of educational video design. Many of the design techniques that are used in educational video today reflect the subjective perceptions of "what works best" acquired through the designer's personal experience and what is considered best practices in the field, rather than empirical evidence (Najjar, 1996; C. D. Wetzel, P. H. Radtke, & H. W. Stern, 1994). Another challenge in educational video design has been to identify information presentation techniques that facilitate higher-order learning, such as transfer of knowledge and structural knowledge acquisition (Gerjets, Scheiter, & Catrambone, 2004). Enhancing knowledge transfer is particularly important because successful instruction should not focus exclusively on the retention of knowledge but should also encourage creative applications of newly acquired knowledge in novel situations (Sternberg & Mio, 2009).

This study was guided by these three research questions:

1. Will the SSW intervention affect the perceived learning difficulty of novice learners in the context of educational video?
2. Will the SSW intervention affect retention of knowledge, knowledge transfer, and structural knowledge acquisition for novice learners in the context of educational video?
3. Will the SSW intervention improve far transfer of knowledge and structural knowledge acquisition to a larger extent than retention of knowledge for novice learners in the context of educational video?

This study attempts to test the following three hypotheses:

1. Novice learners in the SSW video group will report lower levels of learning difficulty than their counterparts in the control group.
2. Novice learners in the SW video group will improve in overall knowledge acquisition (retention, far transfer, and structural knowledge) in the context educational video.
3. Novice learners in the SSW video group will outperform the control group on the tests of knowledge transfer and structural knowledge acquisition, but not on the test of knowledge retention.

To overcome the limitations associated with learning from multimedia materials, cognitive researchers focused on developing and evaluating a number of design principles applied individually to various multimedia learning context. These principles involve the manipulation of characteristics of the multimedia materials and categorized into two groups: the first group comprises strategies aimed at reducing extraneous cognitive processing (i.e., processing that is not related to the instructional goal) such as coherence principle, redundancy principle and signaling principle. The second group aimed at managing intrinsic cognitive processing (i.e., basic processing related to the instructional goal), such as segmentation principle, pretraining principle, and modality principle. These principles are drawn on cognitive theories, such as Sweller's cognitive load theory (Chandler & Sweller, 1991; Sweller, Chandler, Tierney, & Cooper, 1990) and Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2001).

Although applying these design principles to multimedia learning content found to be effective in improving students' knowledge acquisitions (R. C. Clark & Mayer, 2008; R. Mayer, Moreno, Boire, & Vagge, 1999), little research has discussed the implications of these design principles in the context of educational video or when applied together. Therefore, the purpose of the present study was to examine and discuss the implications of applying three multimedia design principles as integrated model to instructional video on students' cognitive and learning outcomes.

Methodology

This study is a quasi-experimental, between-subjects design to assess the effect of the instructional video designed based on the SSW model (independent variable) and students' knowledge acquisition represented by four dependent variables: 1) the perceived difficulty of the learning material, 2) conceptual knowledge acquisition, 3) structural knowledge acquisition, and 4) transfer of knowledge. Learners' prior knowledge was included in all statistical analyses as covariates.

Participants

Participants were 226 undergraduate students enrolled in an introductory entomology course at a large Midwestern university in the United States. There were 110 students in the SSW model group and 116 students in the no-SSW group. Each group was an intact section of the entomology course. Males totaled 132 (*58.4 percent*) and females 94 (*41.6 percent*). Average age was 20 years old ($SD = 3.08$), with mean years in college of 2.3 ($SD = 1.07$). Participants consisted of freshmen, sophomores, juniors, and seniors in non-science majors, such as accounting, history, education, business, and political science. Students attending this course were meeting face-to face once a week and class time was divided between lectures and watching videos related to the topics covered in the course.

Materials

The investigators used a professionally produced video about insects, as well as another version of the same video designed by applying SSW model. Both videos were presented in the DVD format and were 34 minutes long. The DVD was part of the instructors' supplemental materials for the corresponding topic about insects as well as SSW version of the same video. The original video entitled "Insects" was professionally produced by the British Broadcasting Company in 1994. It is part of an educational video series that investigates the insect's life cycle and various tasks insects perform, such as eating, breathing, flying and communicating. The original and the SSW-augmented video included close-up video shots of insects, animations, diagrams, photographs, sound effects, and voice-overs. The investigator obtained a permission to use the video in this experiment through the office of the legal consular of the Learning Resource Center at Tulsa Community College. The TCC legal consular issued a legal justification document stating that the use of this video in this experiment falls under the Fair Use Act for Educators.

The SSW version of the video was modified by applying the CTML principles of segmenting, signaling, and weeding (SSW). The video was divided into five conceptual segments (i.e., segmentation); each about six minutes long. These segments were built-in as part of the video, and students had no control over the sequence of the presentation, playing or stopping them. The order and essential content of both video versions were identical; however the following design principles were applied to the SSW model video:

1. Breaking the video up into 5 segments (i.e., segmenting).
2. Creating a one-screen introduction and summary for each segment and adding text-based cues for the main concepts (i.e., signaling).
3. Removing video fragments that were interesting but non-essential for students to understand the learning materials (i.e. weeding). For example, removing the section about how an animation of morphing an insect into a car was created (a car bug).

Instrumentation

The paper-based materials consisted of a pre-test and post-test typed on 8.5 X 11 inch sheets of paper. The pre-test included a consent form, a one-page demographics questionnaire, a two-page Metacognitive Awareness Inventory (MAI, 52 true/false questions to assess the degree of self-regulated use of learning strategies as possible and difference between the two groups), and a two-page test of prior knowledge (10 multiple choice questions to assess the participants' domain-specific knowledge before showing them the video). The post-test included a one-question self-report of perceived video difficulty (cognitive load measure (Kalyuga, Ayres, Chandler, & Sweller, 2003), a 20-question multiple-choice test covering all major concepts (conceptual knowledge measure), a 5-question multiple-choice test (knowledge transfer measure), and a 20-item sorting task to arrange the main concepts in distinct categories (structural knowledge measure).

The participation in the study was based on voluntary and student who enrolled in the course and decided to take part in the study; they filled the pretest, watched the video and then completed the posttest. Since watching the video was part of the entomology course, students who decided not to participate in the study, they watched the video only, without participating in pre and posttest and without any penalty.

Results

To assess the main effects of the SSW model, MANCOVA was utilized as test of differences and to determine the effect of the SSW model on students' learning outcomes and the perceived video difficulty. MANCOVA results revealed significant effect for SSW model condition, Wilks' Lambda = .84, $F(1,223) = 8.345$; $p< .01$, eta squared =. 16. These results confirmed the previous findings from cognitive science research and found that students who learned from SSW model video reported lower difficulty of the video and scored higher on retention, far transfer and structural knowledge measures compared to students in no-SSW group.

First, students in the SSW model group (*M*=31.20, *SD*=6.173) performed better on gaining overall knowledge compared to the no-SSW group and the difference between the groups was statistically significant, $F(1, 223) = 7.235$, $p = .008$). The results also showed an eta square of .031, indicates that the SSW model had an estimated main effect of 3.1% improvement in the overall knowledge for the participants in the SSW model group.

Second, students in the SSW model group scored higher on the retention test (*M*=15.83, *SD*=2.526) compared to the no-SSW group (*M*=14.74, *SD*=3.051) and the difference between both groups was statistically significant, $F(1, 223) = 7.477$, $p = .007$). The results produced an eta square of .032, indicating that the SSW model had an estimated main effect of 3.2% improvement in total retention of information for the participants in the SSW group.

Third, students in the SSW model group also scored higher on the knowledge transfer test (*M*=4.52, *SD*=.763) compared to the no-SSW group (*M*=3.97, *SD*=1.038) and the difference was statistically significant $F(1, 223) = 19.506$, $p<.001$). The results produced an eta square of .080, indicates that the SSW model had an estimated main effect of 8.0% improve in total transfer of knowledge for participants in the SSW group.

Finally, students in the SSW model group scored higher on the structural knowledge test (*M*=11.98, *SD*=2.442) compared to the no-SSW group (*M*=10.49, *SD*=3.144) and the difference between both groups was statistically significant, $F(1, 223) = 14.614$, $p<.001$). The results produced an eta square of .062, indicates that the SSW model had an estimated main effect of 6.2% improve in total structural knowledge for the participants in that group.

Implications

Educational video has the potential to improve learning in various ways, but it can also be very demanding for learners' cognitive system. In this study, the investigator made use of CTML design principles to create video by applying three of these principles: breaking the videos into small units (segmentation), cueing and summarizing the main information included in the video (signaling), and removing the nonessential information (weeding). The results from the present study support CTML previous research and the underlying assumption driven from it, which suggests that human mind, can only process small portions of large amounts of visual and auditory stimuli at one time. Moreover, results are consistent with the evidence that SSW design principles can improve learning and reduce the perceived learning difficulty for novice learners by focusing their attention on important aspects of the learning material, providing concise cues and summaries about relevant information, and guiding them to engage in processing only the essential information (Mautone & Mayer, 2001; Mayer & Moreno, 2003).

Taking prior research into account, this study suggests several important implications for the design of instructional video. The SSW model found to be an effective way to design instructional video in assisting novice learner to study about insect and promote higher-level learning (i.e. transfer and structural knowledge). So far, similar effect has been inferred mainly based on the effect of individual design principles on learning and with different multimedia learning materials such as animation and audiovisual static presentations. Results of the present study suggest that the same effect can be demonstrated with instructional video, providing convergent validity for the underlying effect of the CTML design principles.

Enhancing knowledge transfer for students in the SSW model group is particularly important because enhancing higher-level learning is considered by many educators to be the ultimate goal of learning. Unfortunately, educational researchers have noted that transfer of knowledge acquisition is not adequately addressed in K-12 classrooms and even in higher education (Burke, 2005). Therefore, the practical effect of the SSW model is not only in enhancing students' retention of the learning content, but also helping them to creatively applying knowledge in new situations.

The variation of students' learning outcomes in the SSW model group suggests that each design principle has its unique effect on the leaning goals and will likely facilitate certain learning outcomes and may lose its potency for others. For example, the results show that students in SSW group gained the highest scores in the transfer of knowledge and structural knowledge measures (as compared to knowledge retention), suggesting that SSW principles promote higher-level learning (Mayer, 2005). Therefore, instructional video designers must consider the relation between the learning outcome and the design principles used in video. For example, the segmenting principle may be most beneficial in terms of scaffolding structural knowledge acquisition, while signaling may prove more useful for helping learners integrate declarative knowledge. Consequently, educational video designers should have a very clear understanding of the learning goals and then design the video accordingly. This could be particularly useful in situations where there is little or no guidance from the instructor (e.g., online learning), or in face-to-face to explicitly focus and guide students on the essential concepts the video is designed to address.

Results of the present study are also consistent with prior CTML research in that adding irrelevant information to a multimedia presentation results in poorer understanding of the content (Mayer & Moreno, 2003). A possible explanation of this result is that in the non-SSW video condition, the nonessential information and the necessity to discern the most relevant content may have created extraneous cognitive load either by competing with the essential content for the limited cognitive resources or by demanding more cognitive resources to process the nonessential content. However, the SSW model helped students to organize their cognitive resources and process essential content more efficiently, leading to more deeper learning and, consequently, higher test scores.

Enhancing students test scores in the SSW model group compared to the control group could also be explained under the CTML framework. First, the segmentation of the video may help reduce students' perception of the task's learning difficulty through chunking the 32 minutes of continuous video content into 5 coherent video segments. Although both groups spent the same amount of time watching the video (32 minutes), the duration of each segment in the SSW condition was relatively short (about 6 minutes) and segmenting the long video contributed to the optimization of learners' knowledge integration. However, in the non-SSW group, learners were not able to process information as efficiently because the continuous stream of novel information without explicit breaks. Second, signaling effect may also help learners in the SSW condition to organize relevant information into a coherent structure and decreased extraneous cognitive load associated with the extraction of semantic cues that were implicit in the original video. Finally, weeding may assist in reducing the cognitive processing of extraneous material and resulted in reduced learning difficulty and higher levels of sustained attention on relevant aspects of the video (Mayer & Moreno, 2003).

Although the content of the video used in both groups was identical, students in the SSW model group reported that the video was significantly less difficult compared to students in the original video group. Consequently SSW model appears to be useful to decrease extraneous cognitive processing and enhance student learning from educational videos. These results highlights the importance of taking into account the limitations of learners' working memory capacity when designing video, especially when learners have not developed domain-specific schemas that help them interpret dynamic visual information (Kalyuga, et al., 2003). Unlike processing print text, which allows the learner to control the pace at which information is "fed" to the working memory; educational video presentations are typically long (20 minutes to 1.4 hours) and are shown to learners without interruptions, in their entirety. Thus, more cognitive support, such as segmenting, signaling, and weeding, is required in situations with limited learner control over the pace, sequencing, and duration of content presentation.

The use of concept-sorting task in the present study as a measure of structural knowledge acquisition has implication for learning outcomes measurement. While retention and transfer measures have traditionally been employed in prior studies to assess learning outcomes in multimedia learning, adding structural knowledge provides an important insight into learning from video. Structural knowledge is considered an essential aspect of deep learning because it involves not only the integration of declarative information into useful knowledge concepts, but also the organization of the implicit patterns of relationships among concepts as well as understanding of the concepts' operational structure within itself and between associated concepts (Tennyson & Cocchiarella, 1986). This study showed that even though structural knowledge scores were relatively low for both experimental groups (students are seldom assessed on structural knowledge), the SSW model did produce a measurable effect on this dependent measure of learning. Thus, an implication for educational video researchers and designers is to determine the utility of various design principles in facilitating structural knowledge acquisition and emphasize it in their instruction.

Finally, applying the SSW model in this study to long video (32 minutes), suggests another practical implication. While prior studies employed shorter animation that varied from a few seconds to a few minutes, the long video used in this study may help students to adjust their metacognitive process to the new video design. It is conceivable that in such long treatment, participants were able to determine the pattern of the SSW video design and adapt to it, enhancing the probability of identification of the intervention effect. In a shorter treatment, however, learners' metacognitive process might not have had the same noticeable effect due to the initial adjustment period it would require. This suggestion should be empirically tested.

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