COGNITIVE LOAD THEORY – SOMETIMES LESS IS MORE

By

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ABSTRACT

This paper represents a review of the literature examining the current research related to cognitive load theory and more specifically the negative aspects of redundant on-screen text. The authors describe working and long-term memory and how both factor into human learning through the facilitation of knowledge transfer. Limited working memory and cognitive load as defined in the cognitive load theory are explored thoroughly. Briefly, the author describes the benefits of including visual and audio components in the design of technology-based instruction based on the split-attention and modality effects of the cognitive load theory. Several studies related to the redundancy effect are presented, all supporting the exclusion of redundant on-screen text in technology-based instruction. Justifications for case by case inclusion of redundant on-screen text are discussed. Recommendations for technology-based instructional design are included.

Keywords: Technology, Learning, Cognition, Modalities, Redundancy

INTRODUCTION

Many modern educators follow a scholastic philosophy that embraces the belief that teachers should master their discipline, continue in research, and center instruction on developed bodies of knowledge. As early as the 13th century, scholastic philosopher Saint Thomas Aquinas promoted these principles to his fellow educators (Gutek, 1995). Although traditional philosophies of education have not changed much over time, the educational system is saturated and forever changed by technological innovations. In the 21st century, technology can be used to assist and sometimes improve the knowledge transfer process. These new and exciting innovations have the potential to maximize learning and significantly reduce the educational divide that can be found between various cultural, religious, and socioeconomic groups around the world today (Solomon, Allen, & Resta, 2003). In order to unlock the educational potential technology can provide, educators must remember the wisdom of Saint Thomas Aquinas and embrace scholarly research and the current body of knowledge that guides the teaching profession. Technological advancements in learning have highlighted some of the limits inherent in the human cognitive architecture. Human intellect, working memory, and the ability to process new information are limited (Clark & Mayer, 2011). The cognitive load built in to an instructional design should be configured so that information is transferred from working memory to long term memory optimally (Sweller, 2008). If not properly integrated, educational technology can easily overwhelm the limited cognitive abilities of the average learner and hinder the transfer process. An analysis of recent studies focusing on the human cognitive load theory has revealed that instructional design incorporating educational technology should include audio and visual components while limiting the use of narration with redundant on-screen text (Clark & Mayer, 2008; Sabine & Kinshuk, 2008; Sweller, 2008).

Human Cognitive Architecture

Like snowflakes, no two humans are the same. Each individual has unique cognitive abilities and learning preferences (Sabine & Kinshuk, 2008), but humans as a species do share common characteristics and a distinctively human cognitive architecture (Sweller, 2008). Herein lies an opportunity for course designers. Certain aspects of the human cognitive architecture are directly related to learning and should be considered when building instructional design strategies. For instance working memory and long-term memory are vital components that have a direct impact on learning.When instruction is designed to include multiple sources of information that can only be understood once the related sources have been mentally processed and integrated into a single concept, a split-attention effect can be created which represents an inefficient use of memory and cognitive processing (Sweller, 2008; van Merriënboer & Ayres, 2005). Another negative effect of course design that ignores human cognitive architecture is the modality effect. Like the split-attention effect, the modality effect involves a complex topic that requires two sources of information to be delivered to the learner (Sweller, 2008; van Merriënboer & Ayres, 2005). When both sources of information are visual in nature such as instruction that includes a picture and written text, the modality effect could lead to cognitive overload (Sweller, 2008; van Merriënboer & Ayres, 2005). A third consideration for course designers is to avoid technology-based instruction that incorporates redundant information because this approach to course design does not take advantage of the human cognitive architecture (Sweller, 2008; van Merriënboer & Ayres, 2005). All three of these instructional design considerations are addressed in the Cognitive Load Theory and will be discussed in more detail.

Humans use working memory to temporarily store and keep active new information as it is received (Sabine & Kinshuk, 2008, p. 307). The average person can only store between five and nine items in this way so working memory is considered to be extremely limited especially when compared to the number of items humans can store in long-term memory (Sabine & Kinshuk, 2008). According to Sweller (2008), instructional designers who ignore the limitations of working memory "are likely to be ineffective" (p. 373). One of the ultimate goals of all instruction is to transfer knowledge to the learner who must then receive the information and successfully transfer it from working memory to long-term memory so the information can be recalled and used when it is needed (Clark & Mayer, 2011; Sweller, 2008).

As previously mentioned long-term memory is used to store information for long periods of time. The sheer volume of information humans are able to store in long-term memory is amazing. Elders who live to be 100 years old can tell stories of their childhood and master chess players can store and recall thousands of chess board configurations (Sweller, 2008). The uniquely human ability to perform skillfully in any number of ways could not happen if long-term memory was not able to store and organize massive amounts of knowledge (Sweller, 2008).As new information is stored and categorized, cognitive schemas are created in long-term memory which provides a vehicle for large amounts of related knowledge to be retrieved and processed quickly without putting an excessive burden on working memory (van Merriënboer & Sweller, 2010).An important consideration when designing technology-based instruction is to select appropriate information for the course content (Sweller, 2008). Even though long-term memory can store an unlimited amount of information, the learner must still understand the content and be able to add the new knowledge to a cognitive schema. When learners experience information overload or the content is too complex for the current stage of understanding, the effectiveness of the instruction is lessened.

Schemas can become progressively more complex as new information is obtained and categorized but each time a schema is recalled from long-term memory it is processed in working memory as a solitary item (van Merriënboer & Sweller, 2010). In this way long-term memory is used to overcome the considerable limitations of working memory. The role long-term memory plays in the architecture of human cognition is so vital that it is now considered to be the central component to the successful transfer of knowledge (Sweller, 2008).

Transferring Knowledge

Storing knowledge in long-term memory is an important aspect to learning but it raises the question regarding the origin of information. Where does new information come from? The process of discovering new information is slow and extremely difficult (Sweller, 2008). Thankfully humans are equipped with everything they need to successfully transfer information from the long-term memory of one person to the long-term memory of another (Torcasio & Sweller, 2010) so knowledge can be preserved in the human race indefinitely (Sweller, 2008). The literature promotes two primary methods used to transfer knowledge: audio and visual channels (Clark & Mayer, 2011; Sweller, 2008). This means humans can learn by using their eyes and ears. Every day people learn by watching and listening and reading the words recorded by others. Technology can be used to assist and sometimes improve the knowledge transfer process but technological advancements in learning have also highlighted some of the limits inherent in the human cognitive architecture. These limitations as well as recommendations for course designers on how to overcome them are addressed in the Cognitive Load Theory.

Cognitive Load Theory

Working memory has one channel to store and process visual information and a second channel to store and process information received audibly (Clark & Mayer, 2011; Sweller, 2008). The combined act of storing and processing information in working memory creates a burden that is commonly referred to as cognitive load (Clark & Mayer, 2011, p. 41). John Sweller (2008) describes three types of cognitive load. The inherent complexity of the information being received creates an intrinsic cognitive load that cannot be reduced without impacting the understanding of the learner (Sweller, 2008). The two types of cognitive load that can be manipulated are extraneous and germane. An extraneous cognitive load is unnecessary and excessive in nature and should be reduced (Sweller, 2008). Germane refers to an ideal cognitive load that does not overload working memory and leads to new information being transferred to long-term memory (Sweller, 2008). It should be noted that the burden of the intrinsic load and an extraneous load (if present) are additive in nature meaning the combined burden can more easily lead to cognitive overload (van Merriënboer & Sweller, 2010). The cognitive load theory acknowledges the three distinct types of cognitive load and forms instructional design strategies for technology-based instruction.Three of the most popular design strategies address split-attention, modalities, and redundant sources of information.

Split-Attention

As mentioned earlier some topics of instruction are so complicated that two sources of information are needed before the average learner can be reasonably expected to grasp the concept. Teaching geometry is a good illustration of a topic that typically requires a visual component in the form of a picture or diagram in addition to a textual explanation. If the diagram of the geometric shape does not include pertinent textual information such as a title, sub-heading, or labeled angles the learner will be required to search for the information in the text and refer back to the diagram, possibly several times before understanding can be obtained. This behavior represents a split-attention effect which requires the integration of two sources of information creating an elevated state of cognitive processing which can lead to an extraneous cognitive load (Clark & Mayer, 2011; Sweller, 2008; van Merriënboer & Ayres, 2005).

In a recent study conducted by Al-Shehri and Gitsaki (2010), 20 English as Second Language (ESL) students were tested in an online multimedia environment for the split-attention effect. Five students were randomly assigned to four groups. Group A was tested using two sources of information in a split-attention format while group B was provided access to an online dictionary in addition to the split-attention format. Group C was presented with integrated information while group D was given access to an online dictionary in addition to the integrated information. Group D outperformedall other groups in the reading comprehension. The Split-Attention groups had to reference the text often during the test and took significantly longer to finish. For these reasons Al-Shehri and Gitsaki (2010) concluded that the groups exposed to the split-attention format exhibited an increased cognitive load which resulted in diminished performance (p. 368).

The appropriate instructional design that can reduce the negative effects of split-attention is to place required text close to required images so the learner is not required to search for and integrate the two sources of information (Clark & Mayer, 2011; Sweller, 2008; van Merriënboer & Ayres, 2005). The result of combining the two sources of information should lead to a reduced extraneous cognitive load.

Modalities

Based on the fact that humans can receive information both visually and audibly and working memory has two separate channels to store and process the two types of information, one best practice for designing technology-based instruction is to present the learner with visual information and audio information at the same time. Sweller (2008) refers to this as the modality effect while Clark and Mayer (2011) refer to it as the modality principle. In essence the total capacity of working memory is increased when the instruction includes both visual and audio components (Sweller, 2008). The modality principle works best when the intrinsic cognitive load is high or put another way, when the material being taught is complex (Clark & Mayer, 2011).

As an illustration we will again refer to the geometry instruction example used to explain the split-attention effect. First it should be noted that if the geometry lesson is complex or the learners have never been exposed to the material, the intrinsic cognitive load will be high for the average learner. If the lesson has been designed to includepictures and diagrams of geometric shapes and text based instruction, both will be processed in the visual channel of working memory (Clark & Mayer, 2011; Sweller, 2008; van Merriënboer & Ayres, 2005). The two forms of visual instruction competing for limited working memory in addition to the high intrinsic load can lead to an extraneous cognitive load which represents an overloaded learner.

The instructional design strategy that can be used to reduce the extraneous load is to convert the text based instruction into audio based instruction (Clark & Mayer, 2011; Sweller, 2008; van Merriënboer & Ayres, 2005). Now the learner will be processing pictures and diagrams in the visual channel of working memory and the audio instruction in the audio channel of working memory. This reduces the extraneous cognitive load allowing the learners to process the high intrinsic load using their newly expanded working memory. This instructional design strategy has recently been tested in the following study.

Erlandson, Nelson and Savenye (2010) tested the effects of replacing a text-based chat communication component in an Educational multi-user virtual environment (MUVE) with a voice-based chat component. The study involved 78 undergraduate students who were currently pursuing a degree at a large southwestern university (2010). The students who participated in the study were volunteers. Their objective was to explore a 3D virtual world for 90 minutes acting as research scientists studying various diseases that were reportedly plaguing the inhabitants of the MUVE (2010). The control group consisted of 39 students who were required to use a text-based chat to communicate with partners inside the game. The treatment group had the same objective in the same MUVE, but they were allowed to use voice-chat for their communication and collaboration. Replacing a visual component in the MUVE with an audio component is in line with the modality principle. Once the in-game activities were complete the students were assessed. The results from a cognitive load self-assessment indicated that by replacing the visual text-based chat with the audio voice-based chat, the cognitive load of the participants was reduced (2010).

The Redundancy Effect

If designing instruction to include on-screen graphics and audio narration increases learning it may be tempting to make the assumption that adding redundant on screen-text would increase the learner's understanding even more. This assumption is linked to the fact that individual leaners can have different learning styles (Sabine &Kinshuk, 2008). Clark and Mayer (2008) refer to this assumption as the "learning styles hypothesis" (p. 137). Learning styles do have a place in education. Over time learners are exposed to information in different forms suchas textbooks or videos, hands-on labs and animated simulations. It is not uncommon for learners to eventually form preferences. The danger comes when instructional designers try to use technology to address multiple learning styles at the same time. Available research supports the cognitive load theory and disproves the learning styles hypothesis that would lead to instruction designed to include narration and redundant on-screen text (Clark & Mayer, 2011).

It has been well established in the literature, and this paper, that graphics use the visual channel of working memory while audio narration uses the audio channel of working memory (Clark & Mayer, 2011; Sweller, 2008; van Merriënboer & Ayres, 2005). The problem with redundant on-screen text is that it also uses the visual channel of working memory which can lead to an extraneous cognitive load (Clark & Mayer, 2008; Sabine & Kinshuk, 2008; Sweller, 2008). Instead of being able to use the entire visual channel to store and process the graphical information the learner is now forced to use the same limited channel to process the graphics and redundant text. Not only is this approach a waste of memory but it also reduces the effectiveness of the graphical information because learners cannot study the graphics if they are reading redundant on-screen text (Clark & Mayer, 2011). Another potential waste of cognitive resources can happen if the learners consciously or subconsciously attempt to synchronize the on-screen text with the spoken words which Clark and Mayer (2011) refer to as "extraneous cognitive processing" (p. 139).

Across the board research has shown that learning is reduced when redundant on-screen text is added to instruction that already includes graphics and narration. Craig, Gholson and Driscoll (2002) used an animation explaining the formation of lightning to test seventy one undergraduate students. The 71 students were split into groups. One group of students were shown the animation with an accompanying audio narration while a second group was given the animation, audio narration and redundant on-screen text. When the presentation was over all students were tested thoroughly. The group of students who were not given the redundant on-screen text produced significantly higher test results (Craig et al., 2002).

Kalyuga, Chandler and Sweller (2004) tested 25 trade apprentices who ranged in age from 16 to 19 years old. Laptop computers were used to deliver the instruction which consisted of diagrams explaining how to calculate the Revolutions Per Minute (RPM) of a drill with additional audio narration or redundant on-screen text. Again the test results were clear. When redundant on-screen text was delivered concurrently with audio narration the learner's cognitive load increased and test scores went down. Kalyuga et al. (2004) concluded that their test results provided empirical evidence that justifies the Cognitive Load Theory.

Jamet and Le Bohec (2007) more recently tested the redundancy effect of the cognitive load theory by testing three groups of learners. All three groups were shown various diagrams dealing with how memory functions. One group was presented with the diagrams and an audio narration but no on-screen text. The second group was presented with the same diagrams and audio narration but the instruction also included full redundant on-screen text. The third group also received the diagrams, audio narration and redundant on-screen text but the redundant text was presented "cumulatively on screen sentence-by-sentence" (Jamet & Le Bohec, 2007, p. 592).

After all three groups finished the instruction a test on retention and a test on knowledge transfer was administered. Another task based assessment was given that focused on the memorization of the diagram. Across the board the test results showed substantial impairment anytime redundant on-screen text was presented to the leaner during the instruction (Jamet & Le Bohec, 2007). According to Jamet and Le Bohec (2007) the results indicated an overload of the visual channel of working memory which is in line with the Cognitive Load Theory (Jamet & Le Bohec, 2007). In this light, it is imperative that course designers intentionally develop technology-based instructional experiences that avoid visual redundancy on-screen.

Exceptions

Based on the architecture of human cognition (e.g. limited working memory with dual channels) technology-based instruction stands to benefit from the use of graphics and verbal narration but redundant on-screen text can overload the visual channel and lead to an extraneous cognitive load. Should instructional designers avoid redundant on-screen text in all situations or are there exceptions to the redundancy effect? The answer to this question is that there will always be exceptions to the redundancy effect because no two learners are the exact same. For example redundant on-screen text may be helpful if the learner is not fluent in the primary language used for instruction (Clark & Mayer, 2011). When verbal narration is used for instruction the learner must be able to receive, store, and process the new information very rapidly or understanding will be impacted. For this reason many learners who are not fluent in a language may prefer written text over verbal narration. Learners who have a hearing impairment may benefit from the addition of redundant on-screen text for similar reasons (Clark & Mayer, 2011). If the impairment is mild the redundant on-screen text may be used for reinforcement or if the impairment is severe the redundant on-screen text may replace the audible narration all together. When language fluency or a hearing impairment negatively impacts the effectiveness of verbal narration the benefits of using redundant on-screen text will outweigh the risk of overloading the visual channel of working memory.

Complexity can also impact the redundancy effect. When the complexity of the learning material is low the intrinsic cognitive load goes down which in turn reduces the risk of redundant on-screen text causing an extraneous cognitive load (Clark & Mayer, 2011; Sweller, 2008). Anytime the intrinsic cognitive load is low the redundancy effect is lessened. For example, prior knowledge can also reduce the intrinsic cognitive load if the leaner is already well versed in the subject matter (Kalyuga et al., 2004; Sweller, 2008). This indicates that if the instruction is being used as a refresher or if the learners have already developed a mature cognitive schema on the subject, redundant on-screen text should not become an issue (van Merriënboer & Sweller, 2010). It should also be noted that in multiple studies the redundancy effect was negated if the pace of the instruction was reduced. The theoretical reasoning is that working memory can store and process an extraneous cognitive load if given adequate time (Clark & Mayer, 2011; Kalyuga et al., 2004).

Although this review is not to be considered exhaustive, these studies represent a slice of salient research studies that have been conducted over the last ten years. The majority of research clearly supports the Cognitive Load Theory andconsequentially, the negative effects of redundant on-screen text.

Summary

There is no doubt that technology can be used to facilitate learning. The optimal integration of technology is more of a challenge and requires insight into the human cognitive architecture(Sabine &Kinshuk, 2008; Sweller, 2008). The ultimate goal of all technology-based instruction is to transfer knowledge to the learners so the information can bepreserved in long-term memory, wherecognitive schemas can be developed (Clark & Mayer, 2011; Sweller, 2008; van Merriënboer & Sweller, 2010). The key to technology-based instruction is to facilitate the knowledge transfer process in a way that leads to a germane cognitive load(Clark & Mayer, 2011; Sweller, 2008; Torcasio& Sweller, 2010). The abundant literature covering human cognitive architecture clearly illustrates how powerful human long-term memory can be while simultaneously highlighting the inherent limitations found in working memory(Clark & Mayer, 2008; Sabine &Kinshuk, 2008; Sweller, 2008). Based on the Cognitive Load Theory, several effective instructional design strategies have been developed that allow course designers to incorporate audio and visual components in ways that lead to an expansion of total working memory which in-turn leads can lead to a reduced extraneous cognitive load(Clark & Mayer, 2008; Sweller, 2008).

Recommendations

Based on a review of the literature the following recommendations for course designers of technology-based instruction could be made. First, when incorporating visual components such as pictures and diagrams, and textual components in the same module of instruction, integrate the two sources of information when possible. If the learner is required to search the text for the information needed to understand the picture or diagram, the split-attention effect is present and constitutes a waste of cognitive resources. Second, evaluate the instruction for elements that could lead to the modality effect. If the intrinsic cognitive load is high and the instruction includes two visual components such as pictures and text, consider replacing the text with an audio narration so an extraneous cognitive load is not created. Thirdly, watch out for redundant sources of information. The literature specifically addressed the negative aspects of designing instruction to include graphics, audio narration and redundant on-screen text. Not only do the graphics and on-screen text compete for limited visual working memory, the on-screen text reduces the effectiveness of the graphics in the process. Also, it should be noted that some learners attempt to synchronize the audio narration with the redundant on-screen text which can create extraneous cognitive processing. Exceptions to the redundancy effect do exist but should only be used on a case by case basis. Overall the literature appears to support the idea that technology can be used to assist and sometimes improve the knowledge transfer process especially when technology-based instruction incorporates best practices found in the Cognitive Load Theory.

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