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Cognitive Function of Multimedia Learning

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Abstract

Multimedia environments consist of verbal and visual representations that, if appropriately processed, allow for the construction of an integrated mental model of the content. Whereas much is known on how students learn from verbal representations, there are fewer insights regarding the processing of visual information, alone or in conjunction with text. Multimedia content has been used in education applications, e.g. in distance learning, to make learning more intuitive, more interactive and more effective than the traditional presentation formats.

Cognitive architectures include a description of memory stores, memory codes, and cognitive operations. Architectures that are relevant to multimedia learning include Paivio's dual coding theory, Baddeley's working memory model, Engelkamp's multimodal theory, Sweller's cognitive load theory, Mayer's multimedia learning theory, and Nathan's ANIMATE theory.

This paper addresses the issue of how to avoid unproductive multimedia instructional practices and employ more effective cognitive strategies. The article ends with methodological suggestions concerning the important role of interdisciplinary research and assessment methods in this are.

Keywords: working memory, multimedia, cognitive load, act-r, dual coding.

1. Introduction

Cognitive theory is borne from the relatively new interdisciplinary field of cognitive science. The term cognitive refers to perceiving and knowing, and cognitive scientists seek to understand mental processes such as perceiving, thinking, remembering, understanding language, and learning. As such, cognitive science can provide powerful insight into human nature, and, more importantly, the potential of humans to develop increasingly powerful information technologies [1].

The purpose of this article is to provide a tutorial overview of cognitive architectures that can form a theoretical foundation for multimedia learning. Multimedia in this context consists of combining words and pictures, but the different formats of words and pictures allow for many possible combinations. This paper addresses the problem that much of what we are currently seeing in multimedia instruction may actually hinder the learning that it claims to promote and then discusses possible ways to improve it.

Baddeley's model of working memory and Paivio's dual coding theory suggest that humans process information through dual channels, one auditory and the other visual. This, combined with Sweller's Theory of Cognitive Load and Anderson's ACT-R cognitive architecture [2], provides a convincing argument for how humans learn, which leads to the question of how multimedia instruction can be designed to maximize learning. Cognitive theory and frameworks like Mayer's Cognitive Theory of Multimedia Learning provide empirical guidelines that may help us to design multimedia instruction more effectively. Mayer argues that the best way to present multimedia instruction is through visual graphics and informal voice narration, which takes advantage of both verbal and visual working memories without overloading one or the other. The six theories are not rivals but focus on different aspects of multimedia learning.

2. Multimodal Theories

2.1 Paivio's Dual Coding Theory

Dual-coding theory, a theory of cognition, was first advanced by Allan Paivio. The theory postulates that both visual and verbal information are processed differently and along distinct channels with the human mind creating separate representations for information processed in each channel. Both visual and verbal codes for representing information are used to organize incoming information into knowledge that can be acted upon, stored, and retrieved for subsequent use [3].
Each channel also has limitations. For example, humans have difficulty simultaneously attending to multiple auditory or visual cues, depending on expertise with the task or prior knowledge with the subject area.

2.2 Baddeley's Working Memory Model

Alan Baddeley and Graham Hitch proposed a Model of Working Memory in 1974, in an attempt to describe a more accurate model of short-term memory. The original model of Baddeley & Hitch was composed of three main components; the central executive which acts as supervisory system and controls the flow of information from and to its slave systems: the phonological loop and the visuo-spatial sketchpad. The slave systems are short-term storage systems dedicated to a content domain (verbal and visuo-spatial, respectively). In 2001 Baddeley added a third slave system to his model; the episodic buffer.
Baddeley & Hitch's argument for the distinction of two domain-specific slave systems in the older model was derived from experimental findings with dual-task paradigms. Performance of two simultaneous tasks requiring the use of two separate perceptual domains (i.e. a visual and a verbal task) is nearly as efficient as performance of the tasks individually. In contrast, when a person tries to carry out two tasks simultaneously that use the same perceptual domain, performance is less efficient than when performing the tasks individually [4].

2.3 Engelkamp's Multimodal Theory

The previous two architectures have focused on the interplay between words and pictures but have not incorporated actions into their design. The role that actions play in instruction has been understudied and is only recently attracting greater interest among cognitive scientists. The multimodal theory formulated by Engelkamp provides a theoretical framework for discussing some of this recent work [5].

3. Instructional Theories

The theories proposed by Paivio, Baddeley, and Engelkamp have implications for instruction. The instructional implications of a limited-capacity working memory have been developed in Sweller's cognitive load theory.

3.1 Sweller's Cognitive Load Theory

Cognitive Load is a term that refers to the load on working memory during instruction. Instruction may be aimed at teaching learners problem solving skills, thinking and reasoning skills (including perception, memory, language, etc.) Cognitive load theory has been designed to provide guidelines intended to assist in the presentation of information in a manner that encourages learner activities that optimize intellectual performance [6]. In Sweller's theory employs aspects of information processing theory to emphasize the inherent limitations of concurrent working memory load on learning during instruction. It makes use of schemas as the unit of analysis for the design of instructional materials.
Sweller argued that cognitive load is reduced by the use of dual mode (visual-auditory) instructional techniques and that the limited capacity of working memory is increased if information is processed using both the visual and auditory channels, based on Baddeley's model of working memory. Intrinsic,

extraneous, and germane cognitive loads form an equation in which the sum total of the three cannot exceed working memory resources if learning is to occur. Following this assumption, Sweller et al. proposed several instructional design techniques based on Cognitive Load Theory. These instructional principles are identified as the goal-free effect, worked example effect, completion problem effect, split-attention effect, modality effects, redundancy effect, and the variability effect.

3.2 Mayer's Multimedia Theory

Research by Mayer is commonly cited to show retention and transfer effects resulting from multimedia when the principles in below are adhered to. These principles stem from cognitive science's understanding of the limitations of working memory and methods for encoding into long-term memory [7].

(1) Multimedia principle: Students learn better from words and pictures than from words alone.

(2) Spatial contiguity principle: Students learn better when corresponding words and pictures are presented near, rather than far from, each other on the page or screen.

(3) Temporal contiguity principle: Students learn better when corresponding words and pictures are presented simultaneously rather than successively.

(4) Coherence principle: Students learn better when extraneous words, pictures, and sounds are excluded.

(5) Modality principle: Students learn better from animation and narration than from animation and on-screen text.

(6) Redundancy principle: Students learn better from animation and narration than from animation, narration, and on-screen text.

(7) Individual differences principle: Design effects are stronger for low-knowledge learners than for high-knowledge learners and for high-spatial learners than for low-spatial learners.

3.3 Nathan's ANIMATE Theory

It is informative to compare the similarities and differences of another approach to multimedia instruction that combined text and animation in a somewhat different way than did Mayer. The purpose of this instruction is to use multimedia to improve students' ability to formulate equations for algebra word problems.

A computer learning environment called ANIMATE helps to establish correspondence by providing animation-based feedback. The simulation provides visual feedback regarding whether the quantitative relations among the quantities and variables in the problem have been correctly specified [8].

4. How People Learn – the Cognitive Sciences

Research over the last two decades has revealed volumes on the subject of how people best learn.

Publication outlines important principles upon which schools should consider redesigning learning:

(1) Student preconceptions of curriculum must be engaged in the learning process. Students have preconceptions and prior experiences with many of the areas of study included in the academic standards. These are stored in long-term memory. Often some of those preconceptions turn out to be misconceptions. Student learning is greatly enhanced when each student's prior knowledge is made visible (that is, cued from long-term memory into working memory). It is at that point the student has the opportunity to correct misconceptions, build on prior knowledge, and create schemas of understanding around a topic. Learning is optimized when students can see where new concepts build on prior knowledge.

(2) Expertise is developed through deep understanding. Students learn more when the concepts are personally meaningful to them. In order to deeply understand a topic, learners not only need to know relevant facts, theories, and applications, they must also make sense of the topic through organization of those ideas into a framework (schema) of understanding. The development of schema requires that students learn topics in ways that are relevant and meaningful to them. This translates into a need for authentic learning in classrooms.

(3) Learning is optimized when students develop “metacognitive” strategies. To be metacognitive is to be constantly “thinking about one’s own thinking,” in search of optimizing and deepening learning. Students who are metacognitive are students who approach problems by automatically trying to predict outcomes, explaining ideas to themselves, noting and learning from failures, and activating prior knowledge.
Despite recent advances, cognitive science is a relatively new field, and thus will undoubtedly continue to evolve as new research is conducted. The real challenge before educators today, is to establish learning environments, teaching practices, curricula, and resources that leverage what we now know about the limitations of human physiology and the capacity explained by the cognitive sciences to augment deep learning in students.
The six cognitive architectures discussed in this article differ in whether theywere developed to explain laboratory findings or to formulate principles for effective instruction. Paivio’s and Engelkamp’s formulations were developed to explain traditional research results based on paired-associates learning and free recall. Baddeley’s working memory model has also been applied to many traditional laboratory tasks such as reaching conclusions from logical reasoning. In contrast, the formulations developed by Sweller, Mayer, and Nathan apply directly to instructional design.

5. Conclusion

Cognitive science provides several empirical theories that provide useful models to suggest ways in which knowledge is constructed and placed in memory. One theory proposed by Baddeley is known as working memory, which temporarily holds and processes information so that it has the opportunity to be stored as representations in long-term memory. The two primary subcomponents of working memory are the phonological loop, which processes verbal information, and the visuo-spatial sketch pad, which processes visual information. Cognitive Load Theory builds on Baddeley’s model of working memory to propose that since the brain can only attend to and process a limited amount of incoming sensory information, it is important to structure instruction in such a way that working memory is not overloaded. Production system theories such as Sweller’s Cognitive Load Theory explain how working memory interacts with prior knowledge to construct new knowledge. Mayer’s Cognitive Theory of Multimedia Learning bases his own research on these theoretical foundations to develop a framework that serves to guide the development of effective multimedia instruction.
Because new developments in multimedia technology increasingly have the potential to overwhelm the apparently limited resources of the human brain, it is important that we begin to seriously consider cognitive research and look for ways to apply it more effectively. The exponential growth in computer-based training will precipitate increasing demand for effective learning design in multimedia instruction. Rather than relying on flashy special effects, it is important that instructional designers begin to work within an empirical framework of principles that are driven by the learner, rather than technology.

6. References

[1] Zheng, R. Z. (2009). Cognitive Effects of Multimedia Learning. New York: Information Science Reference.
[2] Anderson, J. R. (2005). Cognitive Psychology and its implications. New York: Worth Publishers.
[3] Sorden, S. D. (2005). A Cognitive Approach to Instructional Design for Multimedia Learning. Informing Science Journal, 8, 263-279.
[4] Baddeley, A.D. (2003). Working Memory: Looking back and looking forward. Nature Reviews Neuroscience, 4 (10), 829-839.
[5] Reed, S. K. (2006). Cognitive Architectures for Multimedia Learning. Educational Psychologist, 41(2), 87–98.
[6] Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive Load Theory and Instructional Design: Recent Developments. Educational Psychologist, 38(1), 1-4.
[7] Mayer, R. E. (2005). Multimedia learning. New York: Cambridge University Press.

[8] Clark, R. E. & Feldon, D. F. (2005). Five common but questionable principles of multimedia learning. In Mayer, R. (Ed.) Cambridge Handbook of Multimedia Learning. (pp.97-115). Cambridge: Cambridge University Press.