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An Integrated Model of Multimedia Effects on Learning

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Research on multimedia and related instructional technologies over many years has been characterized by inconsistent findings about their effects on learning. This is because of the myriad of contingent factors that have been shown to moderate multimedia effects. This article offers a model that is designed to integrate the main elements identified in the literature and also to describe their key inter-relationships. There are 12 elements in the model, each representing a theoretical construct, which can be operationalized as a variable. Learner style constitutes the independent variable, with learning as the dependent variable. The other elements are visual input, auditory input, learner control, attention, working memory, motivation, cognitive engagement, intelligence, reflection, and long-term storage, each of which is either an intervening or moderating variable or in some cases both. The elements in the model have causal or associative links with other elements. The proposed model is seen as useful in highlighting the complex nature of multimedia effects on learning and in fostering instructional design which addresses this complexity.

A fundamental question about multimedia effects on learning is why some research studies show positive effects, others null effects with some even showing negative effects. There are many studies reporting that educational multimedia can have a positive impact on learning. A meta-analysis by Liao (1998), for example, examined 35 studies and concluded that multimedia-based instruction is superior to traditional instruction. However, it is notable that 10 of these 35 studies showed the opposite, namely, that traditional instruction is superior to multimedia. A subsequent meta-analysis of 46 studies (Liao, 1999) confirmed the overall positive effect of multimedia on student achievement, but found that it largely depends on what type of instruction it is being compared with. Further, a review of 30 experimental studies on the effects of multimedia (Dillon & Gabbard, 1998) found little evidence that it improves comprehension. It seems clear from these contrasting findings that there are many factors involved in moderating the effects of multimedia on learning. This article presents an integrated model that is designed to provide a basis for describing the complex relationships among the relevant variables that together determine the impact of multimedia in different learning situations.

RESEARCH ON MULTIMEDIA EFFECTS

Before the advent of multimedia there was considerable debate, still largely unresolved today, about whether or not media affects learning. Clark (1983) argued that any apparent media effects result from research which confounds the influence of instructional method, that media are "mere vehicles that deliver instruction" (Clark, 1983, p. 445). Later, Clark concluded that "Media and their attributes have important influences on the cost or speed of learning but only the use of adequate instructional methods will influence learning (Clark, 1994, p. 27). Several writers, however, have questioned the value of such "media-centred debate" (Jonassen, Campbell, & Davidson, 1994, p. 31) and suggest approaching the question not in terms of whether media affect learning but rather by asking: "In what ways can we use the capabilities of media to influence learning for particular students, tasks, and situations?" (Kozma, 1994, p. 18).

One instructional technology, which has a reasonably long history in education, is interactive video where the learner's response determines the order and type of content. A meta-analysis of 63 studies of achievement outcomes with interactive video examined 100 effect measures and found that 51 effects were significantly positive and 5 were significantly negative, the remainder being nonsignificant (McNeil & Nelson, 1991). Why the variation in findings? These researchers initially coded 79 independent variables across the different studies but concluded that they had failed to explain much of the variance because of "a myriad of variables that are difficult or impossible to account for in a single meta-analysis" (McNeil & Nelson, 1991, p. 5).

Liao's (1999) meta-analysis coded 17 variables for each of 46 multimedia studies reporting a total of 143 effects on learning, of which 86 (60%) were positive in favour of multimedia, 53 (37%) were negative and only 4 (3%) null. Four of the variables were found to have a statistically significant impact on the effect size: (a) instrumentation, (b) type of research design, (c) type of delivery system, and (d) comparison group. The researcher concluded that overall, multimedia can have a small but positive effect on student learning but added that: "Left unanswered is the question of what factors truly affect the diverse outcomes for different types of instructions" (Liao, 1999, p. 272).

Much of multimedia is based on combining visual and auditory presentation modes. Research on how people process audio-visual information has highlighted many complexities. For example, people have better short-term recall of auditory than of visual information (Penney, 1989) and need narration to get effective instruction from animation (Mayer & Anderson, 1991), but will read a document on screen while ignoring a narrated summary (Grimes, 1990). In the area of audio-video redundancy, according to Lang (1995, p. 86), "Forty years of research has yielded a hodgepodge of contradictory conclusions" with half the studies showing that redundant audio and video channels improve retention of information and half showing redundancy impedes retention. Again, it is clear that many contingent factors are involved. One such contingency is whether or not the redundant information allows dual-coding of information in both propositional and visual form (Dubois & Vial, 2000). Numerous studies confirm that human memory and cognition is based on the separate coding of imagery and verbal information (Paivio, 1991; Mayer & Sims, 1994; Mayer & Moreno, 1998).

There is a growing body of evidence that the "multi" in multimedia can lead to poorly designed instruction that impedes learning. For example, Mousavi, Low, and Sweller (1995) found that presenting instruction in both auditory and visual modes can cause a "split-attention" effect where students have to divide their attention across multiple inputs resulting in reduced processing. Several studies have found that adding audio instructions to visual text and/or graphics does not increase learning (Barron & Atkins, 1994; Beccue, Vila, & Whitley, 2001). Further, Kalyuga and his associates reported that presenting identical information simultaneously in audio and visual form can have a negative effect on learning. These researchers explained their findings in terms of cognitive load theory which postulates that working memory can be overloaded by redundant information (Kalyuga, Chandler, & Sweller, 1999; Kalyuga, 2000; Kalyuga, Chandler, & Sweller, 2001a). From this brief review many factors can be seen that are involved in determining multimedia effectiveness. There is a clear need for an integrated model, which summarizes the key factors and their interdependencies.

INTEGRATED MODEL

The proposed integrated model of multimedia effects is presented in Figure 1. The various conceptual elements designated by the boxes and ellipses in the model, represent constructs at the theoretical level as well as variables at the operational level. Most of the conceptual elements are, in fact, multi-dimensional as indicated by the dot-points which also designate further constructs/variables. The arrows in the model indicate either a causal or an associative relationship between conceptual elements. The full model comprising 12 inter-related conceptual elements (most containing subelements) is clearly very complex. It is argued, however, that such complexity is required so that the model can properly account for the wide variation in the results of research on multimedia effects. For ease of explication the elements in the model can be grouped as follows:

- Multimedia input (three elements: visual input, auditory input, learner control);
- cognitive processing (two elements: attention, working memory);
- learner dynamics (three elements: motivation, cognitive engagement, learner style); and
- knowledge and learning (four elements: intelligence, reflection, long-term storage, learning).

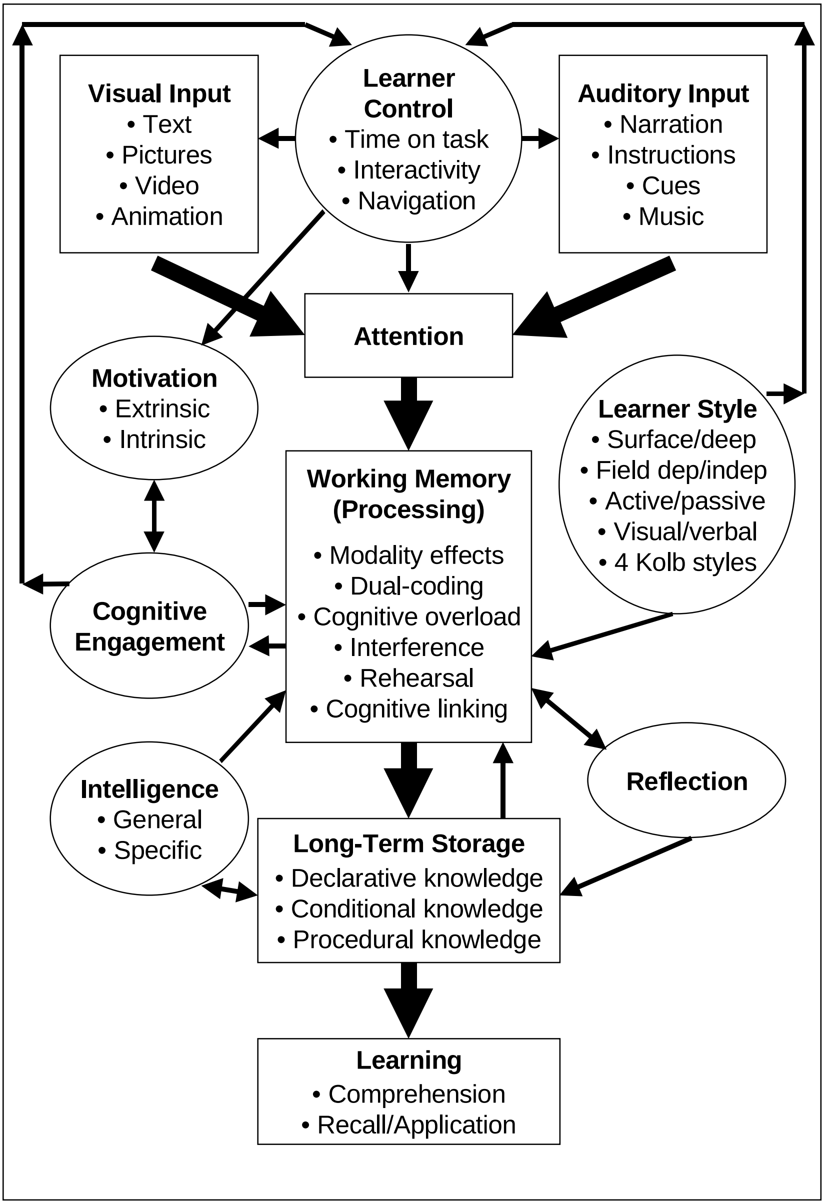

Figure 1. Integrated model of multimedia effects on learning

Multimedia Input

The first group of elements that need to be addressed in an integrated model are those relating to input by which the content of the instructional material is accessed by the learner (Figure 1). The two primary input modalities are vision and hearing. Visual input can take the form of text, pictures, diagrams, video and animation. Auditory input can consist of narration or commentary, instructions, cues, and music. Multimedia can be developed with any combination of these inputs though not all combinations are fully effective.

In addition to a variety of auditory and visual inputs, multimedia provides various degrees of learner control over the inputs. Design features aid the learner in navigating through the various sources of information provided in the multimedia environment (Farrell & Moore, 2000; Tripp, 2001). Links including hyperlinks can enable the learner to access content-rich databases to find more detailed information. Multimedia provides learners with varying levels of interactivity which has been conceptualized in many different ways in the literature (Sims, 2000; Kettanurak, Ramamurthy, & Haseman, 2001). While learner control is generally assumed to be a positive feature of multimedia, there is some evidence that it is less efficient than program control (McNeil & Nelson, 1991). The amount of learner control in multimedia needs to be designed according to the capacities of the learner (Stemler, 1997).

Cognitive Processing

The next group of factors are those involved in processing the information accessed through the input sources (Figure 1). There are two elements for an integrated model here, namely, attention and working memory. Attention serves to focus the learner's concentration on one input at a time though there is evidence that several inputs can be monitored simultaneously at a perceptual level (Hede, 1976, 1980).

The main processing takes place in working memory and it is here that the real complexities of multimedia come into play. The construct of working memory was introduced by Baddeley (1992) and has been widely accepted by multimedia researchers (Niaz & Logie, 1993; Mayer, Bove, Bryman, Mars & Tapangco, 1996; Mousavi, Low, & Sweller, 1995). Working memory comprises an executive processor plus two short-term stores, namely, a "phonological loop" and a "visuo-spatial sketchpad." Note that verbal material (covering both text and narration) is retained beyond a few seconds by "subvocal rehearsal" in the phonological loop (Baddeley, 1992).

There are a number of factors that affect the way working memory processes multimedia information. First, dual-coding enables both auditory and visual inputs to be processed simultaneously resulting in so-called modality effects (Penney, 1989; Mousavi et al., 1995; Tindall-Ford, Chandler, & Sweller, 1997). Another factor, noted earlier, is cognitive overload which occurs when input exceeds the limited capacity of working memory, for example, when identical information is received from more than one input source (Mousavi, et al., 1995; Kalyuga, 2000). Another possible factor is interference where information from one source disrupts semantic processing of information from another source. The retention of information also depends on whether it is subjected to rehearsal. The final factor in working memory is that of cognitive linking which establishes referential connections between verbal and visual representations (Mayer & Anderson, 1991; Mayer & Sims, 1994; Mayer et al., 1996).

Learner Dynamics

There are three conceptual elements relating to learner dynamics. The first is motivation for which there is considerable evidence that it is a key variable in learning (Taylor, Sumner, & Law, 1997). Extrinsic motivational factors such as the design features of a multimedia package are thought to provide some initial incentive for learners to access the material but sustained effort occurs only when they encounter intrinsic motivational factors provided by interesting and challenging content (Najjar, 1998). The latter also leads to cognitive engagement**,** which is the process whereby learners become motivated to take full control of their own learning (Stoney & Oliver, 1999). The integrated model sees the various motivational factors as impacting on learner control, specifically, the time and effort learners devote to engaging with multimedia.

There are a number of ways of classifying Learner Style and this influences the way people access multimedia. Dillon and Gabbard (1998) reviewed three approaches to learner style that have been used in multimedia research. The first distinguishes between field dependence and field independence which determines the extent to which a learner relies on the context in which information is presented. The second approach classifies learners according to whether they are surface processors or deep processors of information, the former relying on memorisation and rehearsal and the latter using content structuring techniques which seem to be more effective in a multimedia environment. The third approach is based on the activity versus passivity of learners—different features of multimedia presentation will be more appropriate for active and passive learners. A fourth approach to learning style is used by Smith and Woody (2000) who distinguished between visual versus verbal processors and report that multimedia is best for learners with a highly visual style. Finally, a number of recent studies have examined multimedia in terms of the Kolb Learning Style Inventory which distinguishes four types, namely, (a) divergers, (b) assimilators, (c) convergers and (d) accommodators (Karakaya, 2001; Kettanurak et al., 2001; Kraus, Reed, & Fitzgerald, 2001). These different approaches to learning style need to be accommodated by an integrated model.

Knowledge and Learning

The final group of factors involves four elements, namely, (a) intelligence: (b) reflection, (c) long-term storage, and (d) learning. Fetherston (1998) advocated the view that intelligence is multi-faceted involving seven different intelligences and the more of these that are stimulated by a multimedia package, the more effective it will be. The process of reflection relates to self-directed learning and entails learners thinking critically about their current knowledge and their learning strategies (Taylor, Summer, & Law, 1997).

The next element is long-term storage where one's knowledge is stored. Long-term storage receives processed information from working memory but also supplies working memory with the basis for cognitive linking whereby connections are established between new content and what is already known. It is appropriate to distinguish between declarative, conditional, and procedural knowledge all of which are involved in the learning process (Yildirim, Ozden, & Aksu, 2001). Research has shown that the relative effectiveness of different multimedia strategies varies with the level of learner knowledge and experience (Kalyuga, Chandler, & Sweller, 1998, 2000, 2001c; Kalyuga, Chandler, Tuovinen, & Sweller, 2001b). The final element in any model of multimedia effects is, of course, learning. The conceptual element of learning comprises the immediate level of comprehension of material accessed through multimedia plus the ability to recall and apply one's acquired knowledge.

DISCUSSION

The integrated model advanced here is admittedly more classificatory and descriptive than explanatory and predictive. This is because it is designed to accommodate a wide range of contradictory research results. However, the model does provide a basis for deriving testable hypotheses about the nature of multimedia effects on learning. It should be noted that the model is not seen as reviving the debate about whether media per se affects learning (Clark, 1994). Rather, the model is compatible with a holistic view of learning as a complex psycho-social interaction between the learner and the instructional designer, a process occurring within a learning environment which includes the delivery media and their attributes (Kozma, 1994).

Whether a particular variable is dependent, independent, intervening, or moderating depends on the context (Sekaran, 2000). In the overall model the dependent variable is learning and the only fully independent variable is learner style (although intelligence could also be construed as independent) (Figure 1). Learner control is conceived of as an intervening variable determined by learner style and also by the moderating variable cognitive engagement, the latter being moderated by motivation which in turn is influenced by learner control (as depicted by the arrows in Figure 1). In other words, how a learner approaches multimedia is hypothesized to depend on their learning style and their level of engagement with the material, the latter being dependent on their level of motivation which can be altered by their experience with the features of the multimedia environment.

Both visual input and auditory input are hypothesized in the model to be intervening variables determined by learner control (Figure 1). This reflects the fact that the specific design and content components of multimedia (text, narration, etc.) do not actually become “input” until the learner devotes time and attention to them. The core of the model is working memory, which is seen as an intervening variable impacted by a variety of moderating variables (cognitive engagement, intelligence, reflection) as well as the independent variable learner style and the intervening variables attention and long-term storage (Figure 1). While there are many factors within working memory that influence how information is processed (as specified by the dot-points), these additional moderating variables add further complexity to its operation.

Information flow in the proposed model is depicted by the heavy arrows while the light arrows show causal or associative linkages (Figure 1). The two-way arrows in the model indicate that the two respective conceptual elements have a reciprocal relationship. For example, cognitive engagement impacts on how information is processed in working memory and that in turn can lead to an increase or decrease in engagement. Similarly, the learner's level of intelligence influences their ability to retain knowledge in long-term storage and also an increase in knowledge increases their specific intelligence (Figure 1). Note that this and all other hypotheses specified by any set of elements and linkages in the model, while derived from the existing literature, are open to further conceptual analysis and empirical test.

The present model may appear to be steeped in cognitivist theory which focuses on the mental processes involved in learning (Jonassen, 1991). Indeed, it does stress the importance of the complex interactions among the various components of human information processing. However, the model is also compatible with the constructivist theory of education which emphasizes self-regulated learning based on personal constructions from experience. The elements of learner style, learner control, and reflection in the model are highly relevant to the tenets of constructivism (Jonassen, 1991). The task of designing a multimedia package based on constructivist philosophy is by no means straightforward (Rodrigues, 2000) and the model should serve as a reminder of the many factors that need to be considered.

The integrated model does not purport to be a unified theory that explains everything about multimedia. The strongest theories in science are those based on only two constructs (e.g., Boyle's Law). With 12 main constructs and numerous component constructs, most inter-related, the present model is weak in overall explanatory power. Its main purpose is to provide educators and instructional designers with a summary of the main factors they need to take into account when developing a multimedia package. Much of the literature on multimedia effects addresses the design implications of research findings. To cite one example, the cognitive load limitations of working memory can be used strategically in the design of effective multimedia (Tuovinen, 2000, 2001a, 2001b). A possible extension from the present model is to develop an application decision-tree with a series of "if-then" branches for the key choices in instructional design (e.g., type of learner styles to be accommodated, level of learner control desired, type of input required, level of learner knowledge assumed, working memory factors anticipated).

CONCLUSION

The author has observed that the extensive literature on multimedia effects is riddled with contradictory findings. It appears that these contradictions largely arise because of methodological confounding by uncontrolled variables which moderate the variables under investigation. The integrated model presented in this article attempts to identify the main variables impacting on multimedia effects. The model is composed of 12 main elements, that is, theoretical constructs which can be operationalized as variables. The independent variable in the overall model is learner style and the dependent variable is learning. The remaining variables are either intervening or moderating or both, namely, visual input, auditory input, learner control, attention, working memory, long-term storage, motivation, cognitive engagement, intelligence and reflection. Most of the 12 elements have a number of component elements which also constitute constructs and variables. Each of the elements in the model is linked to one or more other elements, some having up to eight linkages indicating causal or associative relationships. Because the model incorporates so many elements and highlights their complex interrelationships, it necessarily has limited explanatory power. Nevertheless, it does have the capacity to generate testable hypotheses about each of the relationships it identifies.

There are some exaggerated claims about the benefits of multimedia over traditional instruction. The reality is that the new and emerging instructional technologies used by multimedia are only tools—unless they are applied with careful regard to the complex nature of human information processing, they can have a detrimental effect on learning. The integrated model has the potential to prove useful in fostering good instructional design that properly accounts for the complex nature of multimedia effects on learning.

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