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Towards a New Generation of Multimedia Learning Research

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Empirical research regarding the impact of multimedia on learning can be traced back several decades before the large-scale invasion of multimedia learning resources (like CD-ROM titles and Internet applications) into the educational field and originated from areas outside the educational community. Although the results are not decisive, two generations of multimedia research have contributed to establishing factors that influence effective multimedia design. We summarize the conclusions of the existing research, specifying key theoretical issues, research directions, and weaknesses associated with each generation. Emerging factors, which have begun constituting a third generation of multimedia design and learning research are discussed. Suggestions are made regarding future trends of multimedia design and learning research.

As has been the case in the past with every innovative form of educational technology, the emergence of multimedia educational technology has been accompanied by contradictory views and attitudes. On the one hand there has been an optimistic stand in support of multimedia, which has been based on a range of claims, such as: multimedia systems have the ability to cut down the time of learning while at the same time increase learning effectiveness. On the other hand, contrary positions have maintained a state of skepticism and disbelief regarding the use of multimedia in education.

Multimedia learning research and in general educational technology research has been characterized by inconsistency until now, failing to draw explicit conclusions with relation to the impact that multimedia and technology have on the learning process or to provide a comprehensive framework of design principles at the micro-level for the optimal integration of multimedia elements within a multimedia learning system (Koumi, 2003). Over three decades of research have not managed to resolve the problem satisfactorily. The literature does not lack studies with statistically significant results in favor of multimedia use from which a collection of factors that influence effective multimedia design may be drawn (Najjar, 1998, 2001). However, at the same time it includes a large body of studies that do not provide strong evidence to warrant for the use of multimedia as an effective alternative to learning (Hede, 2002).

Up until the late 1980s, before the large-scale invasion of multimedia into the educational field, a number of attempts, (viewed in this article as the first generation of multimedia research) had been made to comprehend the ways that learners integrate and capitalize on information that is presented to them verbally and visually (Samuels, 1967; Levie & Lentz, 1982). When, in the following years, the rapid progress of technology made it possible for more and more people to start creating and distributing multimedia materials with greater ease and at less cost, an extensive production of educational multimedia content and systems resulted. This large-scale production led to a new and increased interest in the field of cognitive sciences regarding the extent to which these systems contribute to improved learning and more and more empirical studies (a second generation) began to surface.

In this second generation of research, major attention was given to the topics of learning and instruction. Crucial questions were raised regarding whether, under which conditions, and based on which (grounded-in-research) design principles multimedia should be used in education (Reimann, 2003). It was believed at first that multimedia would be capable of facilitating the understanding and learning of complex knowledge domains (such as meteorology, physics, and engineering) by helping a novice learner to distinguish patterns and relationships of the domain (things experts are capable of achieving with ease) (Goldman, 2003). A key issue in this generation was how verbal and visual information should be arranged and presented to the learner to facilitate him/her in "seeing" these patterns and relationships (Mousavi, Low, & Sweller, 1995; Mayer & Anderson, 1991; Mayer & Moreno, 1998, 1999).

However, the relative literature appeared to end up with contradictory results, with some studies connected to educational multimedia providing positive learning results (Liao, 1999) and especially when they were employed to assist the learner in understanding complex knowledge domains (Mayer & Anderson, 1991; Mayer & Moreno, 1998, 1999), and others pointing to insignificant or even negative effects of learning through multimedia (Mousavi et al., 1995; Dillon & Gabbard, 1998). These latter studies reached a significant conclusion: students were not learning through the multimedia systems any better than they were through single media (unimedia)—such as through text—what the multimedia designers had intended for them to learn (Kozma, 1994). This led to the need to examine factors other than the arrangement and presentation of different types of media. More and more a broader range of issues (such as the content itself, the learner's knowledge or style of learning, and others) began to come into view as significant multimedia learning research variables. Currently there is a growing body of studies that are dealing with such topics and are defining a new generation of multimedia research.

This article provides a review of the important conclusions that two generations of multimedia research have contributed to multimedia design, specifying their key theoretical issues and research directions as well as the weaknesses associated with each one of them. Emerging factors, which are currently formulating a third generation of multimedia design and learning research are described. Specifically, the following topics are discussed:

- Which conclusions can be drawn from the media effects debate with respect to how we should be designing multimedia systems and conducting research regarding their effectiveness?

- Which governing learning-theory trends have provided a basis for multimedia design and which characteristics and guidelines are highlighted by each of them?

- Which aspects of the human learning system that concern the comprehension and retention of information presented through multimedia has cognitive science dealt with and how can the features of this system be exploited by multimedia in order to lead to improved learning outcomes?

- What role could the factors that differentiate learners play in multimedia learning research?

- Which are the central issues and research directions that govern the two generations of multimedia learning research, which models are they based on, and which conclusions have they reached?

- Which factors are researchers beginning to focus on and what role could these factors play in facilitating learning through multimedia?

MEDIA AND METHOD: AN INSEPARABLE RELATIONSHIP WITH SIGNIFICANT DESIGN IMPLICATIONS

An issue that has sparked many discussions and studies and is closely associated to multimedia design and research is the media effects debate. This issue, still largely unresolved today, was whether media in and of itself affects learning. Richard Clark and Robert Kozma were fervent contestants on the two opposite sides of the debate. After reviewing an exhaustive number of meta-analyses and studies (carried out from 1912 until the beginning of the 1980s) regarding the influence of media on learning, Richard Clark (1983) reached the conclusion that media are mere vehicles that deliver instruction. Clark alleged that media should not be advocated for their ability to increase learning and that it is basically what the teacher does (i.e., the teaching itself), that influences learning. In short, according to Clark, "there are no learning benefits to be gained from employing any specific medium to deliver instruction; regardless of the media used, which can in the end influence only the cost and speed of learning, what actually contributes to a learning improvement is the instructional method that the teacher employs." This argument instigated many counteractions (Kozma, 1991; Bagui, 1998; Hede, 2002) among which, one that has made a great impact is Robert Kozma's article "Learning with Media" published in 1991. Kozma argued that "medium and method have an inseparable relationship and that they both therefore are key components for the design of instruction."

The value of this debate has been challenged by many (Jonassen, Campbell & Davidson, 1994) on the grounds that the question of whether media affects learning is not a fundamental one and that inevitably it leads to a misconception. The point made is that we should not be seeking to determine that one "super-medium," which will result in effective learning (Jonassen, 1996) and that we cannot expect that our students will achieve significant academic improvement just by coming into contact with that medium (Clark, 1983; Kozma, 1991; Simonsen, Clark, Kulik, Tennyson & Winn, 1987). The problem actually lies in the way we perceive instruction.

For example, if our views were in agreement with Clark's (i.e., that instruction comprises the medium and the instructional method but that these are two separate entities), then we would most probably reach the same conclusion as Clark, that is, that the media alone is incapable of influencing learning but that what does affect learning is the instructional method. If, on the other hand, we supported the notion that, although on a theoretical level separate, in teaching practice medium and method make up an inseparable unit, then we would be closer to Kozma's views, that is, that media does undoubtedly influence learning since it constitutes a necessary component of effective instruction (Nathan & Robinson, 2001). It may even be the case that Clark's and Kozma's views are not in complete disagreement. In fact their positions may appear to stand in contrast and to lead to an opposition exactly because of the different way they view instruction (Nathan & Robinson, 2001). Taking the debate a step further we should also point out that there is a growing body of evidence that multiple media (multimedia) can lead to poorly designed instruction that hinders learning (Hede, 2002). In our opinion media (and most likely multiple media) is undoubtedly capable of facilitating learning but this can only occur if it is selected, designed, and examined on the basis of a number of significant characteristics, some of which we will try to analyze next.

First, we adopt Kozma's opinion that instruction should be considered as an integration of media and methods. This viewpoint leads to the need for careful consideration of the media *together with* the instructional methods adopted when we are designing empirical studies on multimedia learning effectiveness. The simultaneous examination of media and methods will ensure that we do not end up with confounding results as many first generation studies did. As Clark reasoned (1983), evidence regarding media effectiveness will not be valid when experiments allow for changes in other characteristics of multimedia material or systems other than the media (such as the instructional method or content) and yet accredit the learning improvement or obstruction exclusively to the media. *Media and instructional methods therefore need to be examined in close association.*

Second, we agree with Kozma and his advocates (Kozma, 1991; Rieber 2000; Nathan & Robinson, 2001; Hede, 2002), that the fundamental question is not whether media affects learning but *how to take advantage of the various media to make instruction and learning more effective*. We must attempt to understand when (in which situations) media facilitates learning, how to design effective media or how (through which instructional methods) to exploit the attributes of media to support the learning goals that we have set to various learning tasks. At the same time we should focus on what kind of content to use with particular learning tasks, instructional methods, and media, and even consider in which cases it is best to avoid the use of media altogether. In fact, Clark appears to be in agreement with this view when he advises researchers to refrain from producing media comparison studies and to focus instead on necessary characteristics of instructional methods and other variables (Clark, 1983). Only the instruction transmitted through the media has the potential and capabilities of influencing learning and not the media itself (Rieber, 2000) but different media have different instructional capabilities and potential for different situations, learning tasks, students, and forms of content knowledge such as narrative, explanation, description, enumeration of facts, and so forth. (Mayer & Moreno, 2003; Lowe, 2003; Schnotz & Bannert, 2003).

For example animation might facilitate understanding and learning for a particular group of students (such as students with insufficient prior knowledge in the material being presented) when a particular form of content is used and a specific learning task is required within a certain learning situation, for example, a scientific explanation of a complex technical system such as a bicycle tire pump or the explanation of how an algorithm works (Shih & Alessi, 1994; Kann, Lindeman, & Heller, 1997; Mayer & Moreno, 2003). It may, on the other hand, impede learning when either the students, the form of content, the learning experience or the learning tasks chosen are different, even if they refer to the same subject matter and are connected to the same set of learning goals (Anderssen & Myburg, 1992). There is a need to establish a theoretical framework that will help designers to predict under which conditions the employment of specific media is beneficial for understanding and learning and under which conditions and situations this particular media would most likely have detrimental effects.

To some extent, but not adequately, second generation research has taken these factors into consideration. Current multimedia learning research should attempt to deal with these matters much more systematically by investigating the influence of task-appropriate and content-appropriate media on learning and by taking into account a broader range of factors such as the particular characteristics of learners (e.g., low vs. high-prior knowledge, learning style, etc.) or the type of learning situation (e.g., more teacher/system-controlled presentation-form learning experiences based on text and pictures vs. more open-ended, user-controlled forms of multimedia learning experiences such as reality-based learning simulations and immersive virtual reality experiences; Lowe, 2003; Kozma, 2003; Schnotz & Bannert, 2003; Stern, Aprea, & Ebner, 2003).

Third, *we should take into account the fact that learning tasks need to be placed within a specific context of psychological, cognitive, and social processes* (Nathan & Robinson, 2001). A medium used to support a learning task aligned with a constructivist view of learning (where the key factor is to encourage the learner to "construct" his/her own knowledge) will influence learning to the degree that it allows the learner to achieve this procedure (Nathan & Robinson). For example, if a web-based multimedia course or system has been designed within a framework of constructivist learning goals and provides learning tasks and experiences that place learners in the center of the learning process and encourage them to interact with others to "construct" their own knowledge, then the media—in this case the multimedia course—will have succeeded in influencing learning.

Therefore we cannot set out to design multimedia systems or conduct multimedia learning research without taking these factors into serious consideration. In our investigation and summarization of multimedia learning research, we have distinguished a first generation of multimedia research based mainly on the criterion that it lacks association with the issues previously discussed. These issues began to surface more and more during a second generation of research and are currently, as recent studies have revealed, being more methodically dealt with. Multimedia learning material and systems must aim at combining instructional methods and content that exploit the capabilities and attributes of the media to support specific learning tasks and learner characteristics and multimedia learning research needs to point out and closely examine all of the intervening parameters.

In the next section we look at the two governing learning-theory trends that have served as the underlying theoretical basis for multimedia design. We briefly describe the characteristics and guidelines that are highlighted by each of them and relate them to the three generations of multimedia learning research.

MULTIMEDIA AND LEARNING THEORY PRINCIPLES: FROM BEHAVIORISM TO COGNITIVE SCIENCE

Whether we're designing instruction to be delivered the traditional way in the classroom or through an interactive multimedia system, we cannot neglect to take into account one or more learning theories that will serve as the theoretical basis for our instructional design. The systematic and scientific study of how people learn from the 19^{th} century until today has lead to the formation of two dominant theoretical positions, behaviorism and cognitivism. Each makes different assumptions about the way a person learns and remembers knowledge. These two theoretical positions also serve as the governing directions in the field of learning with interactive courseware such as interactive multimedia (Jonassen, 1991; Atkins, 1993; Hannafin, Hannafin, Hooper, Rieber & Kini, 1996; Deubel, 2003).

Behaviorist multimedia design approaches have mostly been associated with the effectiveness of lower-level learning tasks, for example with rapid acquisition of basic concepts, skills, and factual information (Atkins, 1993) (as long as the stimuli and the presentation modes of those stimuli are selected carefully). On the other hand, their positive impact on higher-order learning tasks such as problem solving or transfer has not yet been proven (Deubel, 2003). First generation multimedia research is based on behaviorist design approaches. It is related to lower-level learning processes (such as reading, and remembering information presented through text with or without accompanying pictures) and behaviorist methods of measuring knowledge acquisition (Dwyer, 1972, 1978, 1987; Levie & Lentz, 1982).

On the other hand cognitive multimedia design approaches have mostly been connected with higher-order learning experiences on the condition that they fulfill certain requirements that will ensure the quality of processing that occurs while the learner actively engages with the subject matter (Atkins, 1993). The quality of processing might be affected to the degree to which characteristics and strategies such as discovery learning, problem-based instruction/learning, scaffolding, cooperative learning, and so forth, are applied in the instructional design (Deubel, 2003). The implementation and use of such characteristics within educational multimedia material and systems will most likely lead to improved learning. However cognitive multimedia design approaches appear to have a serious problem; there is no easy way to measure their effectiveness as it is extremely difficult to determine what is going on in the learner's mind. This forces evaluators back on measures such as apparent time on task, apparent engagement with the task presented, and subject estimations of its effectiveness (Atkins; Deubel). Second generation and current multimedia research has been associated with both behaviorist and cognitive multimedia design approaches. Table 1 displays a list of behaviorist and cognitive multimedia instructional design characteristics and strategies.

Table1

Adapted from Deubel, 2003

Behaviorist ID Characteristics	*Cognitive ID Strategies*
• Material is broken down into small, logically discrete instructional steps. • Positive examples are provided as reinforcement and negative to establish conceptual boundaries • The sequence and pacing through the material is usually without learner control. • The required operation, procedure, or skill is demonstrated and broken down into its parts with appropriate explanation before learners are expected to copy the desired behavior. • Performance standards are made explicit. • Assessment is done after learning occurs. • Learners build proficiency from frequent review or revision with check tests at strategic points or repeat practice and feedback.	• Discovery learning or learning to learn, including the ability to question, evaluate one's strategies, and answer question in the content domain. • Scaffolding or the gradual removal of a tutor's support for the individual to become an independent problem solver. • Coaching or instructor-as-coach who may be more knowledgeable and as a mentor may seek to expand the learner's current conceptions. • Problem-based Instruction/Learning where learning is organized around problem solving, rather than around the subject matter. • Learner control over pacing, sequence, and actual content of information presented. • Cooperative learning in which groups work together to solve problems. • Assessment embedded within activities.

COGNITIVE RESEARCH AND MULTIMEDIA DESIGN

Cognitive research deals with how people perceive, learn, remember, and think about information. A cognitive scientist might study how people perceive pictures or why they remember certain facts and forget others, how they learn to speak their language or the way they think when they are playing chess or trying to solve daily problems (Sternberg, 1996). Various issues associated with how learners perceive, remember, and learn information that is presented to them through a multimedia presentation have been studied. For example, many attempts have been made to understand how a learner integrates and learns multimedia information presented verbally and visually for example, through a text enriched with static pictures or through dynamic pictures (animation or video) that are accmpanied by narration (Levin & Lesgold, 1978; Dwyer, 1972; 1978; 1987), or to compare the influence of dynamic against static media for the achievement of particular learning goals (Guttormsen Schar, & Krueger, 2001; Lowe, 2003). The results of these studies have played an important role for the field of multimedia technology and have influenced the definition and direction of multimedia design principles.

Well-known cognitive learning researchers have been concerned with the attributes of the human learning system that affect the comprehension and retention of information presented through multimedia and have examined various ways in which those attributes could be exploited by designers of multimedia systems to lead to improved learning outcomes. The next section provides a brief summary of the main characteristics of human cognitive architecture that cognitive researchers have dealt with along with some of the important instructional design guidelines that they have proposed.

Overcoming the Limits of Working Memory

Limitations of human working memory resources have been identified as a major factor that needs to be considered when instruction is designed. Basing their convictions on cognitive load theory (Sweller, 1989), researchers have suggested that many commonly used instructional procedures are insufficient due to the fact that they require learners to engage in unnecessary cognitive activities that impose a heavy working memory load (Sweller; Sweller & Chandler, 1994). A considerable amount of multimedia material falls under this category. For example we have often witnessed "overloaded" multimedia applications combining an excessive number or inappropriate combination of multimedia elements that result in cognitive overload and impede learning. The basic principle of cognitive load theory is that instructional messages must be designed to keep the cognitive load of learners at a minimum during the learning process, if they are to be effective. Cognitive load theory is best applied in the area of instructional design of cognitively complex or technically challenging material (such as interactive multimedia material dealing with complex knowledge domains) especially for beginners in a given domain. Significant factors associated with efforts to reduce learner cognitive load are prior knowledge, schema formation, automation, and chunking.

Mental schemata and automation cause less pressure on the working memory and therefore help improve understanding. The formation of schemata is facilitated by the existence of prior knowledge whereas the lack of prior knowledge (i.e., appropriate schemata) leads to excessive processing in the working memory. The concept of prior knowledge is fundamental in cognitive science (Di Vesta, 1987; Shuell, 1986; Tobias, 1987; Rieber 2000). Its importance is probably best summarized by David Ausubel (epigraph): “The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.” (cited in Rieber, 2000). Therefore our instructional design must exploit the existence of prior knowledge. Appropriately designed multimedia educational material will help learners activate existing schemata making the information provided to them more meaningful and reducing cognitive load. This will allow them to code and store new knowledge in their memory more easily, as well as retrieve it more effectively. Cognitive load theory has led to significant empirical research from which a number of instructional guidelines have been derived. These guidelines are briefly listed in Table 2 and are important to consider when designing educational multimedia systems.

Table 2

Instructional Design Guidelines Drawn from Research on Cognitive Load

- Carefully analyze the attention demands of instruction. Processing troubles arise when the learner must attend to too many different elements at the same time.
- Use single, coherent representations. These should allow the learner to focus attention rather than split attention between two places, for example, between a diagram and the text or even between a diagram with labels not located close to their referents.
- Eliminate redundancy. Redundant information between text and diagram has been shown to decrease learning.
- Provide for systematic problem-space exploration instead of conventional repeated practice.
- In multimedia instruction, present animation and audio narration (and/or text descriptions) simultaneously rather than sequentially.
- Provide worked examples as alternatives to conventional problem-based instruction.

Adapted from Brent Wilson and Peggy Cole (1996), Cognitive teaching models. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 601-621). New York: MacMillan.

Another theory that has played an important role for the instructional design of multimedia material and has been used to help explain and ameliorate working memory limitations when verbal and visual information is presented to the learner is dual coding (Paivio, 1971, 1986, 1991). Paivio suggested that there are two cognitive subsystems or channels, one specialized for the representation and processing of nonverbal objects/events (i.e., imagery), and the other specialized for dealing with language. Learning is better when information is processed through these two channels instead of one. Connections can be made only if corresponding nonverbal and verbal information is in working memory at the same time. Information processed through two channels is called referential processing and has an additive effect on recall (Paivio, 1991; Mayer & Anderson, 1991; Shih & Alessi, 1996). This happens because the learner is able to create more cognitive paths that can be followed to retrieve the information. The dual coding theory attempts to give equal weight to verbal and nonverbal processing. This theory has been strongly criticized by cognitive researchers who support propositional theories, that is, the notion that memory is propositional in nature and that it is the relationship among propositions that gives rise to meaning (Kintsch, 1974). Nevertheless, dual coding has served as the basis for the instructional design of a large amount of educational multimedia software and systems as well as for a significant portion of second generation multimedia research (Mousavi, Low, & Sweller, 1995; Mayer & Anderson, 1991; Mayer & Moreno, 1998).

ESTABLISHING FACTORS THAT DIFFERENTIATE LEARNERS AND CONTENT

Admittedly, the closer that instruction and educational content are adapted to the needs of the learner, the more efficient and effective the learning will be. Educational researchers have been concerned about the implications of different learner traits for instruction for many decades (Tobias, 1990; Kolb, 1984; Bruner, 1966; Gagné, 1967).

Thus, one of the key issues in the field of educational technology has been how to design adaptable multimedia environments that are capable of accommodating diverse learner requirements. This means creating systems that are able to provide individualized instruction and designing and distributing the multimedia content through this system according to characteristics such as learning goals, prior knowledge, aptitude, cognitive styles, learning styles, and so forth. Within this framework a new approach called adaptable or personalized learning has emerged. The basis of this approach is the incorporation of alternative procedures and learning strategies that can be selected by learners and the primary criterion for the categorization of such systems is the kind of adaptation. Hence, we refer to macro-adaptable systems, which, generally, attempt to determine learner aptitudes before the commencement of the educational process and micro-adaptable systems that diagnose different learner characteristics throughout the instruction (Brusilovsky, 2003; Park & Lee, 2003).

Macro-adaptable systems are based on a set of personal characteristics most important of which are considered to be: (a) the intellectual ability of the learner, (b) the learner cognitive and learning style, (c) the prior knowledge that the learner has, and (d) the motivation of the learner. In the case of micro-adaptable systems the number and the specific characteristics of the mistakes made by the learner during instruction serve as the adaptation criteria. Consequently, according to these mistakes, the models that perform the micro-adaptations provide for modifications that are related to: (a) the type (specific content, level of difficulty, etc.) and the amount of multimedia content which is going to be presented to the learner in the following stage of instruction, and (b) the presentation sequence of the content. Clearly there is no distinct borderline between these two types of systems given that they both borrow characteristics from one another. Numerous studies have been conducted to clarify and determine the range of different learner characteristics and, in general, to establish factors that might serve as the basis for personalized instruction as well as to agree on the types of adaptations that ought to be the outcome of these differences (Chou & Lin, 1998; Chuang, 1999; Ross & Schulz, 1999; Riding & Rayner, 1998).

To date multimedia learning research has only limitedly focused on factors that differentiate learners. The vast majority of empirical studies that have been carried out consider learners as a unified single set, thus failing to reach statistically significant results when one or another type of multimedia content is used. In other cases the results appear to be statistically significant, but it becomes apparent that for this positive result to be produced, the variable "content" was merged with the medium that provides the multimedia information and possibly even with the learner characteristics (cognitive style, prior knowledge, motivation, etc.). In many cases, some of these factors are, indirectly or directly, detected by researchers (Mayer & Moreno, 1998; Schnotz & Bannert, 2003). Thus, a crucial issue would be to clarify the variables that intervene and result in either statistically or nonstatistically significant results. Within this framework researchers have begun to focus their efforts on the emergence, definition, and elaboration of parameters that determine the characteristics and properties of the content and the instruction as well as parameters that describe the learner, and that contribute, more or less, to the effectiveness of the medium. Undoubtedly, the next important step would be to blend these factors together within new theoretical frameworks and models.

In the past, the majority of educational technology systems did not have the capabilities of providing adaptations. In contrast, the current development of educational environments has made a shift towards the use of learning objects that are based on the incorporation of meta-data and consequently permit the "intelligent" treatment of both the content and the learner (IEEE LTSC, IMS, SCORM). Thus, on a technical level, it is now possible to create open environments that offer personalized learning experiences. Third generation multimedia learning research studies have already begun to focus on these issues by introducing and examining concepts such as *computational efficiency*, *learning style*, *cognitive style*, *prior knowledge*, and so forth.

TOWARDS A NEW GENERATION OF RESEARCH

After examining a large body of research regarding multimedia learning, we have categorized them in terms of two significant periods or, what we have referred to in this article as, generations. We also distinguish a third generation that is currently emerging and is moving researchers towards hopeful new directions (Table 4).

First Generation: Research Related to How Learners Integrate and Capitalize on Information that Is Presented to Them Verbally and Visually

These studies originated from areas outside the educational community for example, psychology, art, motion pictures, advertising, and so forth (Arnheim, 1954; Gombrich, 1969) and gradually passed over into that field before computers and multimedia systems began to be used for educational purposes. However, their results have had a significant impact on educational multimedia design and research (Spaulding, 1955; Levin & Lesgold, 1978; Levie & Lentz, 1982). The goal was to examine the influence of different media such as text, sound, and pictures on the human cognitive system. However the studies conducted during this period focused primarily on combinations of texts and pictures. Significant efforts to summarize first generation multimedia research results were made by Levie and Lentz, Dwyer and his associates (1972, 1978, 1987), and Rieber (2000). Researchers tried to comprehend how people learn through this media, how memory operates on it, (e.g., the way memory perceives, stores, and allows for the retrieval of words and pictures) and tried to discover and propose ways of improving these operations. The main conclusion of this research was that text information is remembered better when it is illustrated by pictures than when there is no illustration (Levie & Lentz, 1982; Levin, Anglin, & Carney, 1987). These findings were generally explained with Paivio's dual coding theory (Paivio, 1986). Also Rieber (1990, 2000) and Dwyer and Dwyer (2003) have provided the most exhaustive reviews regarding the impact of dynamic pictures on learning.

The vast majority of first generation research often tried to attribute results only to the media used, ignoring the existence of the underlying instructional method employed and neglecting to place the medium within the broader scope of the learning situation (involving the learning task and its attributes, the learner characteristics, etc.). It, therefore, failed to recognize the existence of the media-method relationship and this is why it very often reached invalid conclusions (Clark, 1983). Studies were based on the behaviorist approach to instruction/learning with an orientation towards lower-order learning tasks and the acquisition of declarative knowledge through prose (i.e. they focused primarily on whether the media could help learners understand and remember information such as facts and ideas presented to them through text or pictures). They did not deal with the issue of whether media could facilitate higher-order learning tasks such as problem solving and they did not examine the outcomes of learning from diverse forms of content such as scientific explanations or descriptions of complex knowledge domains.

Second Generation: Research Related to the Way Verbal and Visual Information Should be Arranged and Presented

The 1990s brought about an explosion of educational multimedia materials. During this period there was an increased interest in the cognitive approach to instruction/learning, however many second generation studies still focused narrowly on what we would characterize as more passive behaviorist designs for example, the presentation of text with or without accompanying pictures—static or dynamic—that required no behavioral or social activity on the part of the learner (Mousavi, Low & Sweller, 1995) excluding more highly-interactive user-controlled learning environments. However, some of the distinctive researchers of this generation (Mayer & Anderson, 1991; Mayer & Moreno, 1998, 1999) focused on how to design multimedia messages to promote, what they called, meaningful learning. These researchers maintained that although their multimedia designs were passive, they were planned in such a way, so as to foster appropriate cognitive activity (i.e., that they encouraged students to build meaningful mental representations, an instructional approach they labelled as cognitive constructivism). Also, these second generation studies attempted to move away from testing plain fact learning by measuring higher-order learning abilities, such as transfer and problem solving.

The key issue of second-generation multimedia research was on how verbal and visual information should be arranged and presented to the learner to facilitate them in recognizing patterns and relationships that distinguish a novice learner from an expert in a given knowledge domain. Researchers attempted to deal with these issues and to propose guidelines that would help learners make the necessary connections efficiently and effectively and techniques that would allow them to overcome the limitations of human working memory resources while trying to make these connections. The work of Richard Mayer and his associates, who elaborated the dual coding theory to provide evidence for why pictures support, under specific conditions, the understanding of physical phenomena or technical systems, is representative of second-generation research efforts This research concluded that arrangements of verbal and visual information that highlight important relationships, remove irrelevant information, and manage the information so that learners' working memory resources are not overloaded, tend to improve learning. Mayer proposed that there are three processes in which the learner needs to engage in, if meaningful learning is to occur, whether from visual (static or dynamic), verbal information, or both (i.e. to select relevant words and images, to organize them into coherent verbal and visual representations, and to integrate corresponding verbal and visual representations). Figure 1 summarizes this significant work (Mayer, 2001).

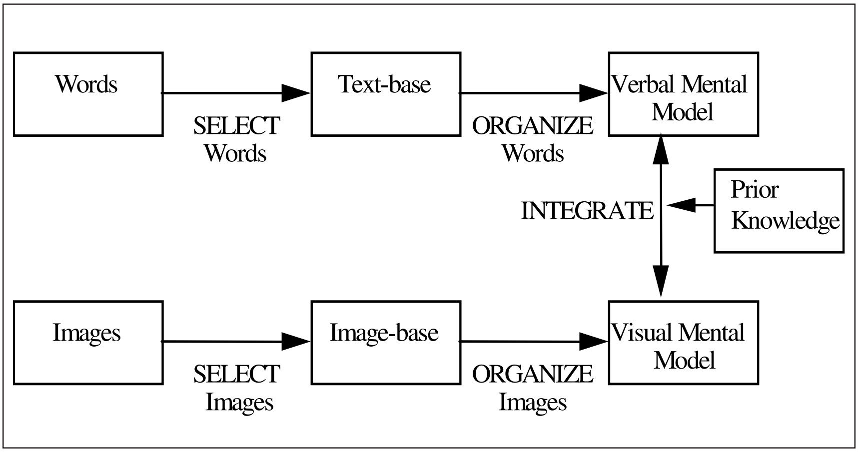

Figure 1. A cognitive theory of multimedia learning

Second generation studies have yielded significant theories, models, and principles for designing multimedia such as Baddeley's (1986) expanded view of working memory, Sweller's (1989) cognitive load theory, and Mayer's (2001) model of multimedia learning. Table 3 displays the *five principles of instructional design for fostering multimedia learning* that have been derived and tested from the cognitive theory of multimedia learning (Mayer & Moreno, 2003).

Table 3

Principles for the Instructional Design of Multimedia Based on the Cognitive Theory of Multimedia Learning

1.	The multiple representation principle states that it is better to present an explanation in words and pictures than solely in words.
2.	The contiguity principle is that it is better to present corresponding words and pictures simultaneously rather than separately when giving a multimedia explanation.
3.	The coherence principle is that multi-media explanations are better understood when they include few rather than many extraneous words and sounds.
4.	The modality principle is that it is better to present words as auditory narration than as visual on-screen text.
5.	The redundancy principle is that it is better to present animation and narration than to present animation, narration, and onscreen text.

An Emergent Generation: Current Issues and Future Trends

A new generation of multimedia research is currently emerging and a shift is being made towards new models and theories that are expected to provide the insights necessary to advance multimedia research in promising new directions. Ideally, this research should lead to a comprehensive framework of principles at the micro-level for the design of effective multimedia learning systems. Some of the topics that multimedia learning research is currently focusing on are: instructional design across all media versus instructional design unique to a particular medium (based on media enabled affordances), computational efficiency, active processing, support for processing, prior knowledge, cognitive load, motivation, and cognitive/ learning styles. Each will be briefly discussed next.

- *Instructional design across all media*: We have already elaborated on issues connected to the media effects debate and have emphasized the need to examine media and methods mutually. A large number of researchers find that there is a higher value in trying to agree on how to design instructional messages across various media (Van Merrienboer, 1997; Najjar, 1998, 2001; Mayer, 2003) instead of examining the effects of media per se—such as asking whether it is better to learn from a computer than from a book. Referring to the presentation of multimedia educational content through words and pictures, Mayer focused on the issue of *methods across media* and summarized good instructional design across media in four important design principles: (a) adding pictures to words, (b) eliminating extraneous words and pictures, (c) placing words near corresponding pictures, and (d) using conversational style for words. However, there may be aspects of instructional design that are unique to a particular medium because that medium enables instructional methods that other media cannot make available (e.g., computers enable interactivity to a much greater extent than books). Research will need to focus both on instructional design principles applicable across media as well as on principles connected to particular media because of the particular methods and affordances for information presentation that those media make possible.

- *Computational efficiency*: Certain representations of information may be very well-suited to particular learning tasks while ill-suited for others that require the learner to first transform the information (to match the task demands) before using it, something that would normally place additional processing demands on learners and may even lead to his/her inability to make the necessary transformation. According to some researchers (Schnotz & Bannert, 2003; Kozma, 2003) the ease with which a learner can extract the necessary information from a certain content representation to deal with a particular task has to do with the *computational efficiency* of that specific representation. For example, several informationally equivalent pictures could visualize the same subject matter in different ways. This area of research focuses on determining the effects that the selection of different forms of visualization would have on the structure of the mental representation created during the comprehension process and also focuses on the computational efficiency of these different representations for specific learning tasks.

- *Active processing*: Media environments do not cause learning; active cognitive processing by the learner causes learning. If learners are not actively processing the information in an attempt to make sense of it, then the accurate design of multimedia and the conformity between media affordances and task demands, may not make much of a difference. Multimedia research is currently exploring ways of promoting active cognitive processing. For example, Mayer (2003) proposed instructional design methods that work across media and that foster active processing and Kozma (2003) proposed engaging learners in scientifically authentic discussions around representations as a way of supporting active cognitive processing.

- *Support for processing*: Another line of research is focussing on the need to determine the effect that different forms of help have for different learners. Goldman (2003) called attention to the fact that different forms of support or help encourage different kinds of processing, and that care needs to be taken to make sure that the kind of processing being supported, is consistent with the demands of the outcome task performance. The effectiveness of various kinds of support is mediated both by the kind of task and the knowledge level of the learner. For example, with respect to task, Seufert (2003) found that her help conditions had different effects that were determined by whether the learners had to recall material or answer comprehension questions. She also found that learners with different levels of prior knowledge react differently when help is given.

- *Prior knowledge*: The effects that prior knowledge has on learning though multimedia is a prevailing issue in current multimedia research, both in terms of how it is associated to successful active processing as well as on how it should be supported (Kozma, 2003; Lowe, 2003; Stern et al., 2003). The research clearly portrays the limiting effects of prior knowledge indicating that the problem of overcoming the way that a novice learner treats multimedia content of a complex domain is complicated and is not simply a matter of presenting the appropriate material or instructing the learner to make use of a specific strategy. Novice learners need to be supported in going beyond the surface features and engaging in deeper active processing that will permit them to perceive and distinguish the underlying principles and concepts. For example, Kozma had students engage in discourse about different representations and Lewalter (2003) encouraged students to generate think-aloud protocols to engage them in active processing. Future research will need to indicate effective ways of supporting learners with different levels of prior knowledge when learning through multimedia environments.

- *Manipulating Germane or Intrinsic Cognitive Load:* Until now researchers in the area of cognitive load have focused on how to design instruction so as to decrease extraneous cognitive load and have ignored the possible positive impact of exploiting germane or intrinsic cognitive load. A shift is currently being made towards studies that examine these effects (Kirschner, 2002; Sweller, 1988; van Merriënboer, Schuurman, de Croock & Paas, 2002; Bodermer and Ploetzner, in press). Whereas extraneous load results from information and activities that do not contribute to the process of schema construction and automation, germane load is related to information and activities that foster these processes (e.g. tasks that are relevant to schema acquisition through increased effort and motivation). Therefore, whereas extraneous load hurts learning, germane load facilitates learning. An area of this research is currently focusing on how to design instruction so as increase germane cognitive load. Another area is currently investigating the possibility of manipulating intrinsic cognitive load. The manipulation of intrinsic cognitive load is an entirely new approach in instructional design and is particularly interesting not only because it has been proposed by the "fathers" of cognitive load but because it contradicts their initial views since the idea presently supported is that it is possible to decrease intrinsic cognitive load, at least artificially (Bannert, 2002). This can be achieved through the appropriate sequencing of the learning material (appropriate information sequencing). For example, Pollock, Chandler and Sweller (2002) examined the manipulation of intrinsic cognitive load of learners dealing with complex knowledge domains by proposing a method they called the "isolated-interacting elements procedure" and concluded that cognitive load had decreased.

- *Motivation*: Another key variable that influences learning through multimedia is motivation. Studies have shown that extrinsic motivation (e.g., grades or external rewards) does not have significant effects on learning and especially for adult learners. On the contrary, there is evidence that intrinsic motivation (e.g., interesting and challenging content) encourages the learner to become cognitively engaged with the multimedia material and improves learning (Najjar, 1998, 2001).

Table 4

Research Progress Regarding the Impact of Multimedia on Learning

	Central theoretical issues and research directions	Models proposed	Underlying theories	Characteristics
First Generation Early 1900's – mid 80's	Research related to how learners integrate and capitalize on information that is presented to them verbally and visually	• Information processing model • Single-code model • Dual-code model • Sensory-semantic model	• Gestalt theory and other picture processing theories • Paivio's dual coding theory • Propositional theories	• Failure to recognize the existence of the media-method relationship • Studies based mainly on the behaviorist approach to instruction/learning • Orientation towards lower-order learning tasks (i.e. fact learning instead of problem solving).
Second Generation Mid 1980's-Late 90's	Attempts to arrange verbal and visual information in ways that facilitate learners to "see" patterns and relationships in the information presented	• Baddeley's expanded view of working memory • Mayer's model of multimedia learning	• Cognitive load theory • Cognitive theory of multimedia learning	• Increased interest in the cognitive approach but research focuses more on behaviorist designs failing to take into account more interactive user-controlled environments • Research regarding the combination and arrangement of media yielded important conclusions for multimedia learning design and research • Research does not examine other important factors such as the content itself or the learning style of the learner
Future Trends Early 21st century	Studies that aim for a deeper understanding of the impact of multiple forms of representation on learning by taking into account learner and content characteristics	• New emergent models		• The research is currently examining the suitability of specific instructional designs in relation to the medium and the instructional method • Researchers are experimenting with diverse representations of informationally equivalent content • Factors that differentiate learners (prior knowledge, cognitive/learning style, motivation, etc.) and also the support required by different learners are taken into account

- *Cognitive and learning styles*: Multimedia learning research has not satisfactorily focused on the impact that particular learning/cognitive style dimensions have on learning and has not managed to identify robust relationships between learning/cognitive styles, instructional methods, and different forms of content. There is a need for further research to determine a framework for designing effective adaptable multimedia learning environments that will be compatible with particular learning preferences, strengths, weaknesses, and behaviors of students, and will lead to efficient and better learning. Obviously new technologies such as learning objects and ontologies used within the semantic web framework will enable a more multidimensional approach, integrating a broader range of variables such as the ones previously discussed. (See Table 4 for summary of the preceding sections.)

CONCLUSION

Multimedia learning studies carried out until recently have ignored important factors that could influence the appropriate selection of media and have thus failed to yield conclusive multimedia design guidelines. We have attempted to summarize key issues, characteristics, and weaknesses of this research. Multimedia learning research is currently attempting a deeper understanding of how a broader range of parameters could play a positive role in the design of effective multimedia environments.

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Note

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