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ABSTRACT

Recent studies have emphasized the significant implications of multimedia for the learning process. Even those researchers who take a less enthusiastic stand do not hesitate to assent that when blended with suitable pedagogical techniques and a proper design, the combined use of multiple media for the viewing and study of educational material can enhance the quality of the learning environment. This paper presents research and development efforts to design a pedagogically sound multimedia Web-based learning interface. Taken into consideration are recent findings from the area of cognitive psychology regarding the use of text, animation, and voice. The logic is based mainly on the presentation modality effect and the principles of spatial and temporal contiguity. The state of the learner's prior knowledge is considered to be of critical importance. The paper presents a flexible user interface supporting the use of animation and voice as default modalities and the existence of text in the same interface as an essential part of the learning process. The SMIL language is used for the implementation of the Web-based interface. (Contains 21 references.) (Author/AEF)

Designing a Pedagogically Sound Web-based Interface: The Critical Role of Prior Knowledge

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Abstract: In this article we present our research and development efforts to design a pedagogically sound multimedia web-based learning interface. We take into consideration recent findings from the area of cognitive psychology regarding the use of text, animation and voice. The logic is based mainly on the presentation modality effect and the principles of spatial and temporal contiguity. We consider the state of the learner's prior knowledge to be of critical importance. We present a flexible user interface supporting the use of animation and voice as default modalities and the existence of text in the same interface as an essential part of the learning process. The SMIL language is used for the implementation of the Web-based interface.

Introduction

Recent studies have emphasized the significant implications of multimedia for the learning process. Even those researchers who take a less enthusiastic stand do not hesitate to assent that when blended with suitable pedagogical techniques and a proper design, the combined use of multiple media for the viewing and study of educational material can enhance the quality of the learning environment. In this article we discuss the theoretical background and the development efforts which have led us to create a flexible interface design that is used for a series of graduate and post-graduate courses.

We distinguish two stages in the learning process:

- the presentation of the instructional material, for which we can assume learners have no prior knowledge and
- that material's study and critical investigation

We seek to provide an integrated support for both stages via the same user interface which will combine the use of animation, voice, and text labels on the one hand for the presentation of the course material to the learners; and alternatively, the use of hypertext and pictures for its in-depth scrutiny. We analyze the reasons that have led us to the adoption of this particular interface design based on the findings of cognitive psychology studies. Commencing with the notion of working memory, we pursue ways to optimize its limited resources, in order to use them as guidelines for our design decisions. Understanding working memory limitations and sensory modality benefits is essential in order to create courses that may reduce cognitive load and enhance the learning process. To this extent, cognitive psychology theories such as Paivio's dual coding theory (1971, 1986, 1991) and Baddeley's model of working memory (1986, 1992) as well as recent evidence provided by cognitive load psychologists can serve as the basis for the instructional design of multimedia courses that will facilitate learning.

The flexibility of the user interface is a crucial matter. Learning outcomes can be increased by creating an interface that provides a combination of modes and modalities from which to select, according to the prior knowledge of the learner.

The Internet has been chosen as the implementation environment due to the additional capabilities it has to offer to the learner and SMIL has been selected because of its ability to synchronize and coordinate diverse multimedia elements.

Finding ways to overcome the limits of working memory

According to the traditional three-stores model of memory (Atkinson and Shiffrin, 1968), a way to conceptualize memory is the following: a) one part of memory, known as *sensory memory*, is capable of storing limited amounts of information for very brief periods of time b) a second component, *short-term memory*, is capable of storing information for somewhat longer periods of time but is also of relatively limited capacity and c) a final constituent, called *long-term memory*, is of very large capacity and capable of storing information for very long periods of time, perhaps even indefinitely.

Working memory is defined as being the part of long-term memory, which also comprises all the knowledge that has been recently activated in memory including the short-term memory. This implies that memory comprises three concentric circles, the inner one corresponding to short-term memory, the intermediate circle to working memory and the exterior one to long-term memory. Information resides within long-term memory, and, when activated, moves into long-term memory's specialized working memory, which will actively move information into and out of the short-term memory contained within it (Sternberg, 1996).

Many memory theorists have assumed that working memory comprises multiple memory systems, which most frequently are associated with auditory or visual processing. For example, one of the most acceptable models of working memory proposed by Alan Baddeley (1990) consists of at least the following: a) a visuospatial sketchpad, which briefly holds and deals with visual images and b) an articulatory (phonological) loop, which briefly holds inner speech for verbal comprehension and for processing verbal information. It is believed that the first two systems process their different types of information in a largely independent and parallel fashion.

In relation to the role and characteristics of working memory, our basic suppositions are the following: a) working memory has a limited capacity and duration, that is, we are able to hold and process only a few items of information at a time, b) working memory includes an auditory working memory and a visual working memory, according to Baddeley's theory, c) each system operates in parallel d) meaningful learning occurs when a learner retains relevant information in each system and is able to make referential connections between them (Mayer & Anderson, 1991).

Prior knowledge, Schema acquisition and Chunking

An average person can retain up to a few chunks of information at a time in working memory. Working memory is believed to be capable of storing seven plus or minus two chunks of information at a time (Miller, 1956). In other words, we can think about only five to nine distinct items at any given time. A general way to overcome the problem of limited capacity of working memory is by creating a schema. A schema is identified as a cognitive construct that allows us to treat multiple elements of information as a single element classified according to the manner in which it will be used (Bagui, 1998). Therefore, a schema puts less pressure on working memory, facilitating understanding. Schema acquisition is facilitated by the existence of prior knowledge. Learners who know a great deal about a subject have more well-developed schemata for incorporating new knowledge.

Dual coding and the sensory modality effect

With his dual-coding theory, Alan Paivio (Paivio, 1971, 1986, 1991; Clark & Paivio, 1991) suggested that information is processed through one of two generally independent channels, modes or codes. That is, our imaginal and verbal mental representations may be viewed as two different codes (analogue and symbolic), which organize information into knowledge. Learning is better when information is processed through 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 (Mayer & Anderson, 1991; Paivio, 1967, 1991; Paivio & Csapo, 1973). This happens because the learner is able to create more cognitive paths that can be followed to retrieve the information.

The research to date thus suggests that dual-mode input (verbal and nonverbal) helps people learn. But humans can also input information through various sensory modalities. Recent studies have addressed the problem of the combination of modes and modalities that should be preferred in order to promote meaningful learning. For example, should an animation (nonverbal mode, visual modality) be accompanied by an explanation presented as a narrative (verbal mode, auditory modality), an explanation presented as on-line text (verbal mode, visual modality), or by both of these forms of explanation simultaneously?

Drawing from Baddeley's (1992) theory of working memory and Sweller's (1988, 1989; Chandler & Sweller, 1992; Sweller, Chandler, Tierney, & Cooper, 1990) cognitive load theory, several researchers have shown that working memory capacity can be enlarged by using dual-modality presentation techniques (Mousavi, Low, & Sweller, 1995; Mayer & Moreno, 1998, 1999, 2000).

This evidence supports the view that instructional designers should not only be concerned about combining verbal and nonverbal information consistent with Paivio's dual coding theory; it is essential that they take into consideration the role of sensory modalities when designing multimedia presentations with pictures and words. Mixed modality presentations are superior to the most integrated text and visual presentations (Moreno & Mayer, 1999).

The contiguity principle

The contiguity principle was proposed by Mayer & Anderson (1992) as a way of increasing the effectiveness of multimedia instruction when words and pictures are presented contiguously in time or space.

They proposed the use of the term *spatial-contiguity effect* to refer to learning enhancement that results when text and pictures are physically integrated or close to each other rather than when they are physically separated. One interpretation of this result is that students might be missing part of the visual information while they are reading the on-screen text or, vice versa, missing portions of the text while focusing on the pictures. This forces the learner to search for relations between them. The cognitive load associated with this search is extraneous (Mousavi, Low, & Sweller, 1995).

Similarly, the term *temporal-contiguity effect* has been proposed for cases when visual and spoken materials are temporally synchronized resulting again in the enhancement of learning. In these cases, learners are able to hold a visual representation in visual working memory and a corresponding verbal representation in verbal working memory at the same time, allowing them to build referential connections between them, consistent with the dual coding theory. Therefore, differences in synchronicity between verbal and nonverbal materials that need to be integrated in a lesson also affect learning.

Evidence associated with the spatial contiguity effect is provided by several studies (Mayer, 1989a, 1989b; Mayer and Gallini, 1990).

Therefore, another critical aspect of designing instructional software, is to physically integrate the corresponding pictorial and verbal information in a multimedia lesson as much as possible, both spatially as well as temporally.

Two alternative combinations for presenting information based on the learner's prior knowledge

The previous discussion has led us to adopt two different and complementary approaches for presenting instructional material. We take into consideration two states of the learner's knowledge domain: a) no prior knowledge and b) prior knowledge.

There appears to be an enhancement in learning with multimedia, especially for learners with low prior knowledge for whom the rich multimedia environment may also positively influence motivation and engagement. Mayer (1993) believes multimedia information is more effective for learners with low prior knowledge or aptitude in the domain being learned because it helps them build a cognitive model or to connect the new knowledge to prior knowledge.

On the contrary, learners with high domain knowledge have a rich source of prior knowledge that can be connected to new knowledge. In other words, they can make referential connections or build cognitive models with text alone. Furthermore, it is also believed that for learners with prior knowledge in the domain being learned, textual information may force them to expend more effort to read and understand the information resulting in improved long-term encoding of the information (Najjar, 1996).

In the following sections we discuss the characteristics and advantages of each of the two combinations.

Hypertext and pictures

Reading text is a complex process. Learners expend more effort when reading, in order to understand information. This results in improved long-term encoding of the information.

In many cases, the use of text alone is not sufficient to help the reader understand concepts and ideas. It has been proven that by incorporating pictures within text, the learning process is enhanced. Visual illustrations make abstract ideas and complex information more concrete and easier to comprehend. Pictures seem to allow very rich cognitive encoding that allows surprisingly high recognition rates (Najjar, 1996).

The combination of text and pictures is effective because it allows for the concurrent coding of verbal and non-verbal information. There has been evidence to show that adding voice to textual presentation degrades learning.

Animation, voice and text labels

Voice is a more realistic and natural mode of presenting information than displayed text, because of the perception of the person behind the voice and the verbal loop (acoustic) we use to store information. Voice does not distract visual attention from stimuli such as diagrams, and is therefore more engaging. It is good for conveying temporal information (Shih & Alessi, 1996).

Despite the potential advantages discussed above, voice suffers from a) the problem of being ephemeral. Text remains in front of the eyes of the reader for a longer period of time. This makes it more suitable than voice when studying and critically analyzing the educational material. Voice lasts only for an instant in time and is more difficult for a learner to control and b) the problem of being difficult to search through for a specific piece of information, something with does not occur in the case of text. The above characteristics point to the view that text is more appropriate for the in-depth investigation of the educational material.

Animation is a motivational way to present information visually. Studies (Najjar, 1996) have shown that information presented in this form of animation appears to be more effective for learners without prior knowledge or aptitude in the domain being learned. In contrast, learners with high domain knowledge have a rich source of prior knowledge that can be connected to the new knowledge. In this case, we could exploit the advantages of combined text and picture presentation techniques.

By using text labels, we facilitate the creation of a schema by giving a cue to learners to focus their attention on the most important points during a certain portion of a narration. The combination of animation and voice is effective because we use non-verbal and verbal information through two sensory modalities.

The interface design

The above research has important implications for the design and practice of multimedia instruction and has served as the basis for the particular user interface design we have adopted. On the one hand, an effort was made to be consistent with the findings of previous studies of working memory resource limits and cognitive load principles. On the other, we have tried to create a flexible interface that can accommodate diverse learning preferences. Flexibility refers to the learner's ability to select a different presentation style from the one initially recommended.

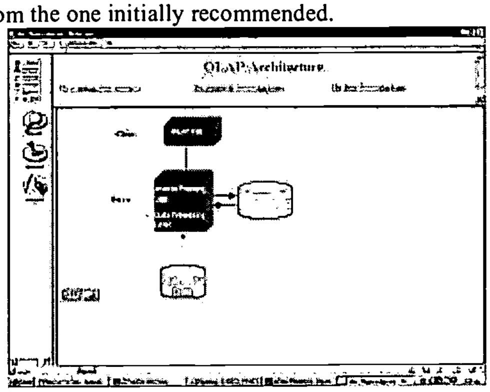

Figure 1

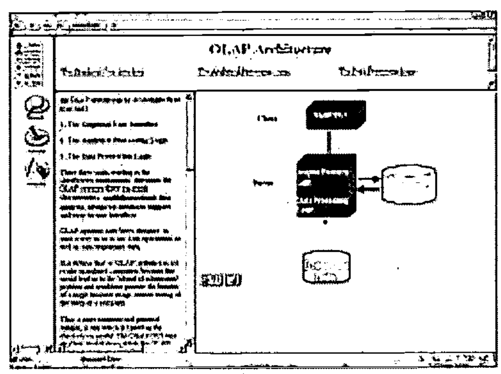

Figure 2

Figure 1 shows the default user interface displayed to the learner upon commencement of a typical instructional unit. The screen has been divided into three frames, one of which (the frame containing the text and static pictures) is not initially visible to the user. In trying to benefit from the processes of schema acquisition and chunking, we have taken care not to present learners with too many different pieces of information or ideas at the same time.

Each lesson has been divided into smaller chunks of related information called *instructional units*. The top frame contains the title of the lesson as well as links to associated chunks which comprise the particular lesson. The frame below the title contains the multimedia content including animation, explanatory text labels as well as the accompanying auditory information. The explanatory text labels have been incorporated into the animation, in accordance with the principle of spatial contiguity, ameliorating the ephemeral characteristic associated with voice. This frame also includes buttons for controlling the flow of the presentation. For example, the learner can pause and restart the animation and voice, change the volume of the voice, etc. Links to related chunks of information are also provided through the use of hot spots (temporal or spatial links) on the diagram. This navigational feature is supported by the SMIL language (discussed below).

The learner can reveal the hidden frame, as shown in Figure 2. This allows for simultaneous viewing of on-line text and animation with the option of listening to the corresponding narration.

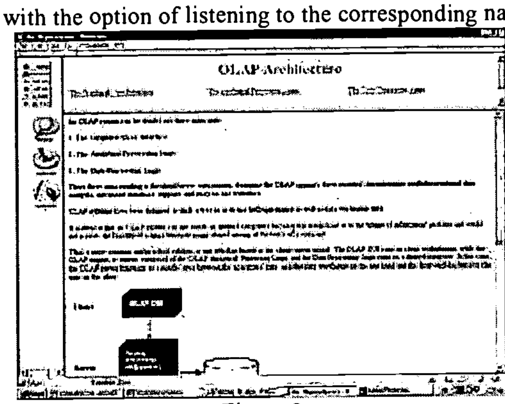

Figure 3

Figure 3 portrays an alternative presentation mode. After the learner has viewed the presentation once (the recommended but not obligatory viewing method), the animation frame may be completely closed so that the learner may study the material in the form of text together with accompanying static pictures.
This process is believed to:

- initially increase learner motivation and engagement during the first viewing stage when prior knowledge of the domain being learned is still nonexistent or at a considerable low level,
- increase learning outcomes during this first stage through a combination of animation and voice and,
- have a positive impact on understanding and retention of the presented material due to the use of text and static pictures in the second stage of its viewing.

Smil and other implementation issues

The implementation of the flexible user interface for the multimedia material is based mainly on the SMIL Language. Using SMIL, it is possible to define screen regions, associate media objects with the regions, and synchronize the appearance of media objects.
The main reasons that we selected SMIL were:

- it can integrate and co-ordinate many diverse types of multimedia information, synchronizing one or more animation files with voice and also text labels,
- we are able to define spatial and temporal links
- it can be considered as an "open", platform-independent technology based on W3C XML.

One of the fundamental problems encountered during the implementation of a multimedia, Web-based course is undoubtedly the limited bandwidth of the Internet. This is perhaps one of the main factors that justify the lack of extremely high-quality multimedia material. We use streaming technology to address this problem.
The product selected was RealServer created by Real Networks. The specific streaming technology makes use of the RTSP (Real Time Streaming Protocol) instead of the HTTP protocol. Figure 4 shows the architecture of the system. There are two servers: a Web server provides conventional html pages while a streaming media server supplies rich multimedia content to the learner.

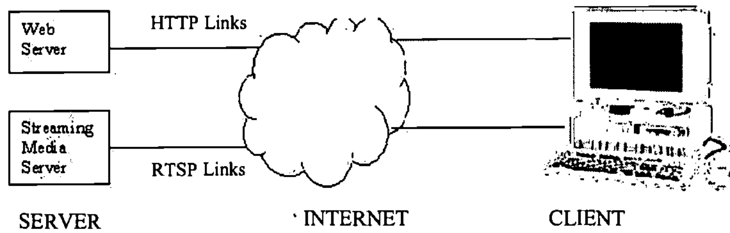

Figure 4

Conclusion

Until recently on-line courses available to university students worldwide were in the form of text-based material with static pictures.
Recent studies have provided evidence for the claim that multimedia has a positive effect on the learning process. However, we need to take into consideration many factors regarding the way learners receive, encode, store and process information. In addition, a central matter of concern seems to be the level of prior knowledge. Bearing this factor in mind, we have proposed a specific user interface design suitable for use through the Internet.

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